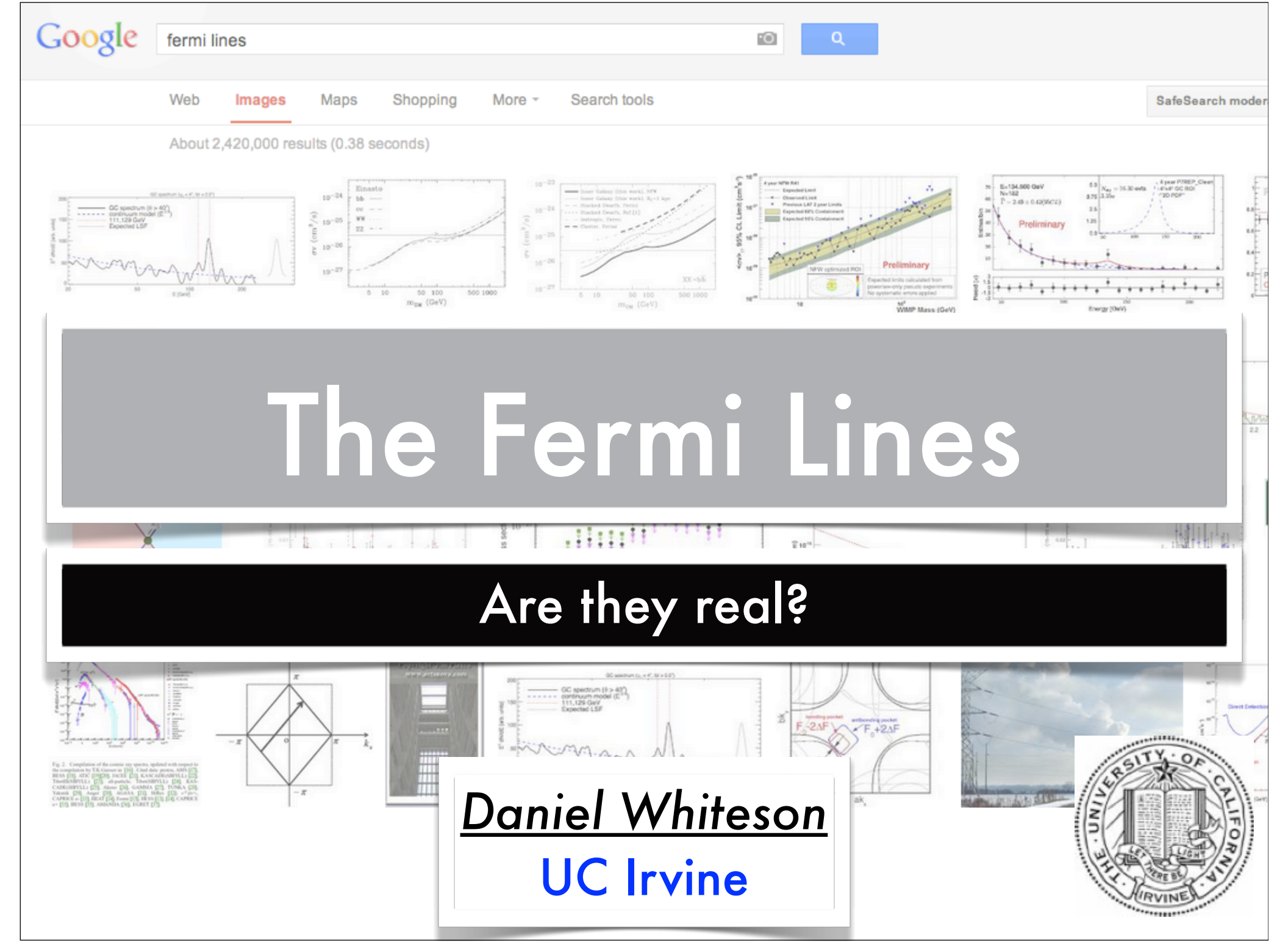


The Fermi Lines

Are they real?

Daniel Whiteson

UC Irvine

Disclaimer

I've been doing collider physics....

Search for resonant top plus jet production in $t\bar{t}$ + jets events with detector in pp collisions at $\sqrt{s} = 7$ TeV

Measurement of ZZ production in pp collisions at $\sqrt{s} = 7$ TeV and limits on anomalous ZZZ and $ZZ\gamma$ couplings with the ATLAS detector

Search for a heavy particle decaying to a top quark and a light quark in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

Search for pair-produced heavy quarks decaying to Wq in the two-lepton channel at $\sqrt{s} = 7$ TeV with the ATLAS detector

Search for same-sign top-quark production and fourth-generation down-type quarks in pp collisions a $\sqrt{s} = 7$ TeV with the ATLAS detector

Search for Dark Matter Candidates and Large Extra Dimensions in event photon and missing transverse momentum in pp collision data at $\sqrt{s}$ =7 Te ATLAS detector

Triangulating an exotic T quark

Search for a heavy vector boson decaying to two gluons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

Su

Search for down-type fourth generation quarks with the ATLAS detector in events with one lepton and hadronically decaying W bosons

... I am not (yet) an astro-physicist!

Outline

I. Introduction
II. The line
III. One line or two?
IV. No continuum
V. Instrumental studies
VI. Source of the photons

DM: what do we know?

unknown unknown

known unknown

known known

What do we hope?

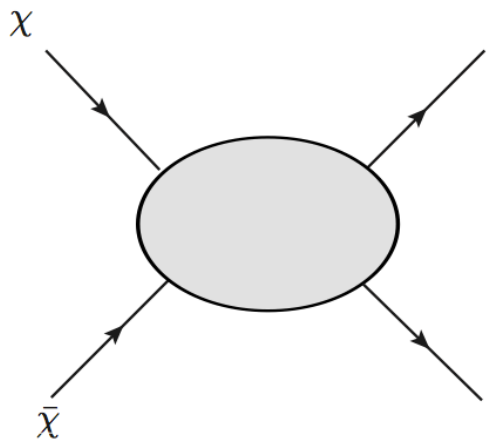
<u>Non-gravitational interaction</u>

Weak-level interaction

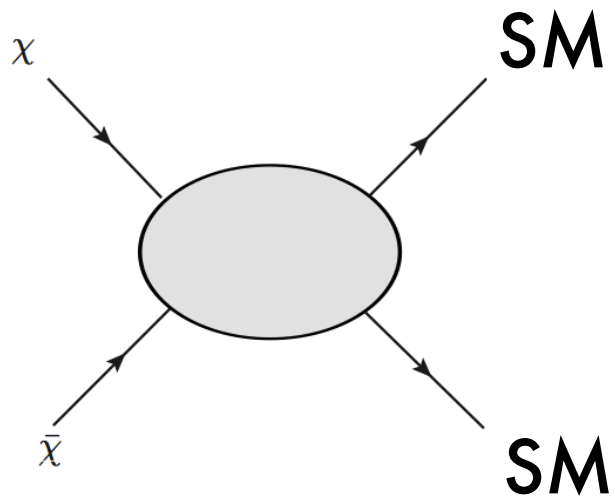
Mediated by massive particles

Gives the right relic density

Interaction

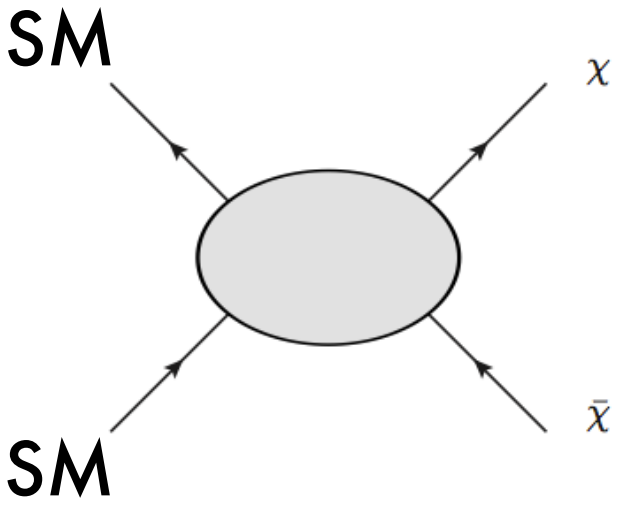


Interaction

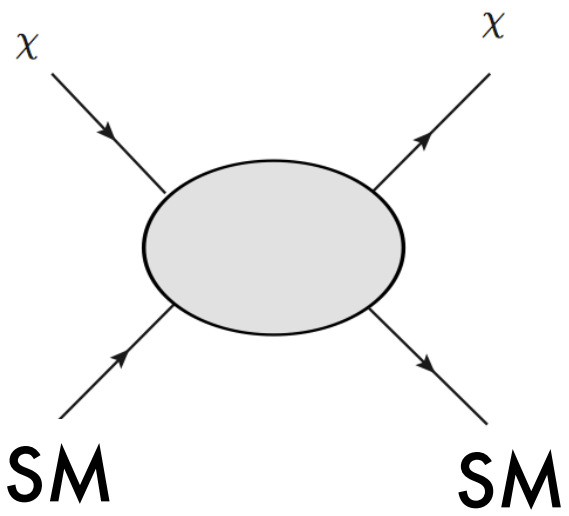


Probes

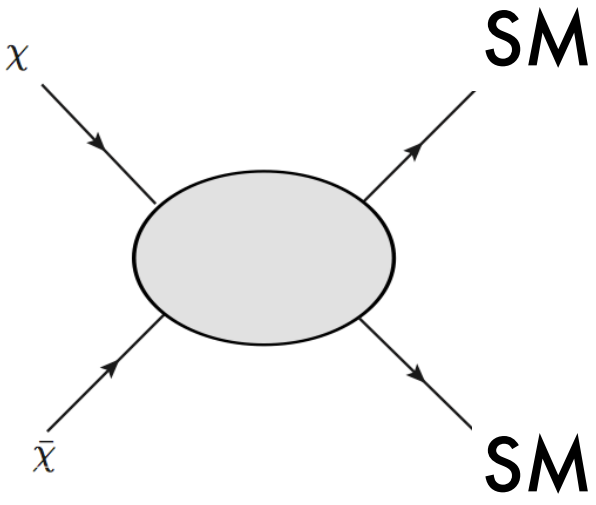
Collider
(ATLAS etc)



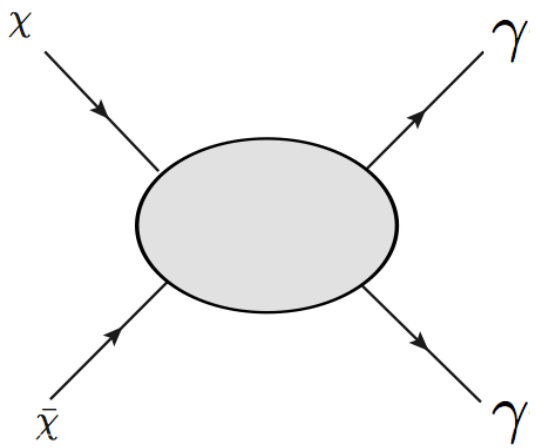
Direct
(Xenon etc)



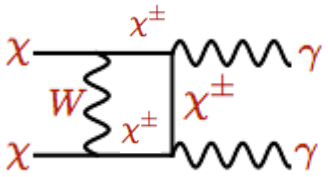
Indirect
(FermiLAT etc)



Photons

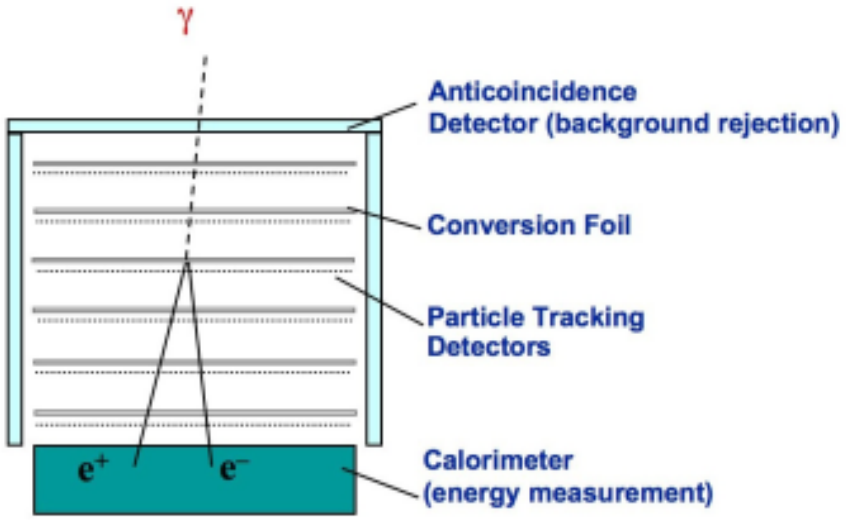


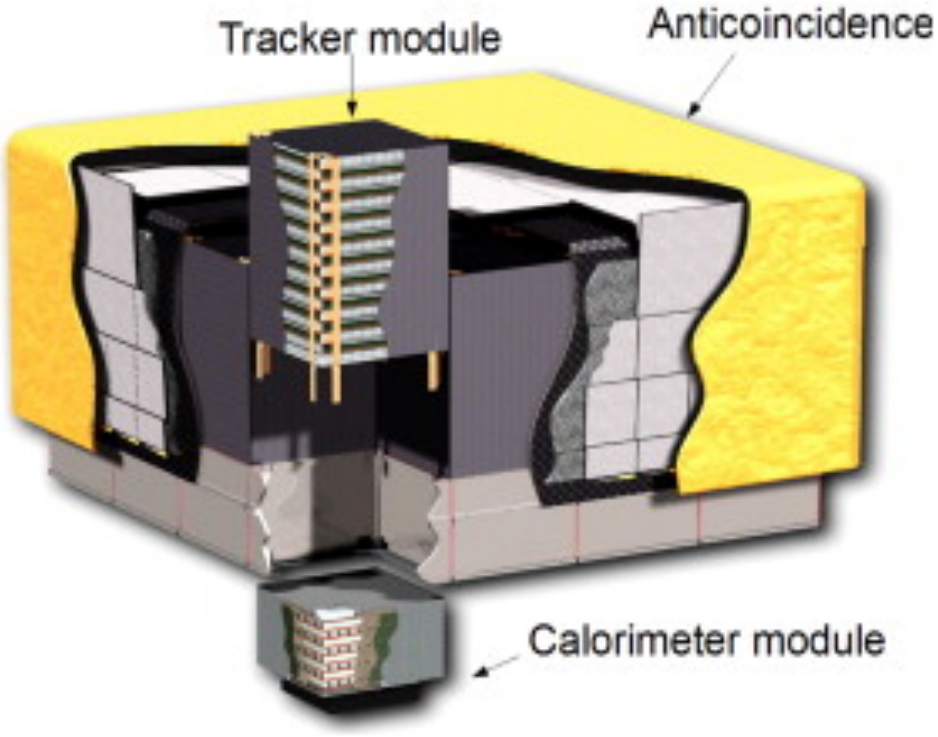
$$E_\gamma = m_\chi$$



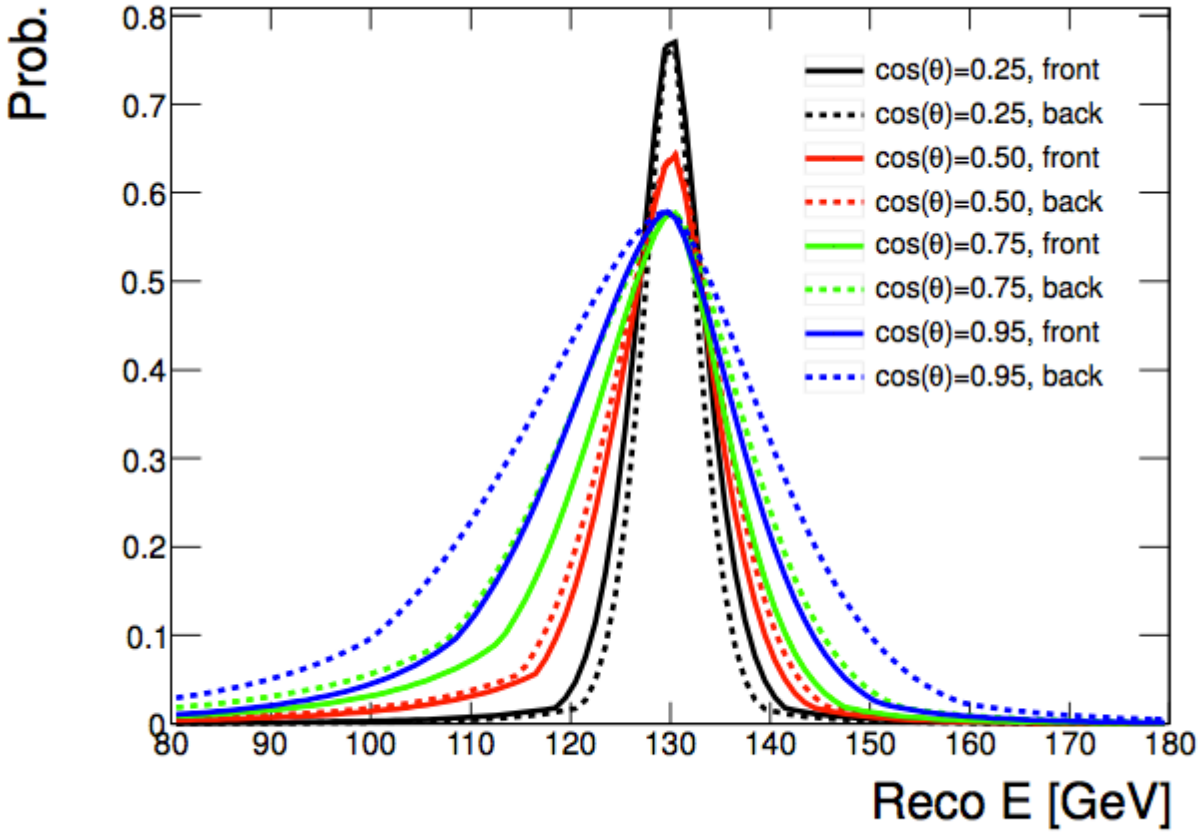
Fermi

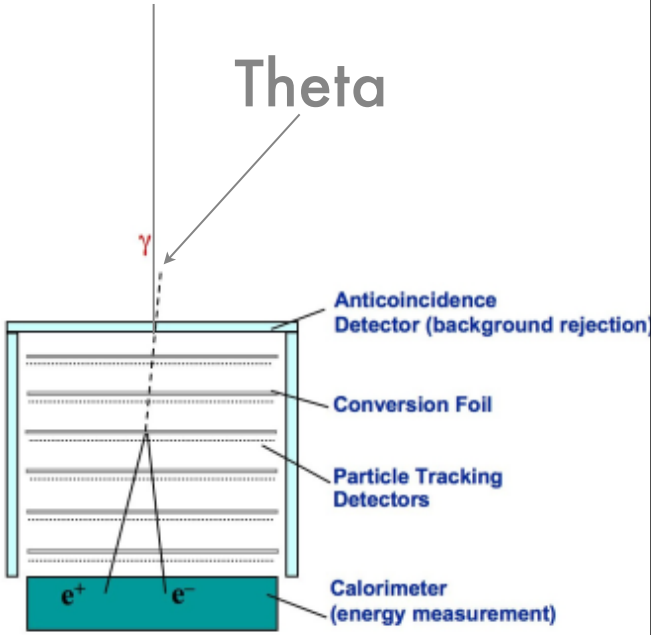
Detector


γ
Anticoincidence
Detector (background rejection)
Conversion Foil
Particle Tracking
Detectors
e+
e−
Calorimeter
(energy measurement)


Tracker module
Anticoincidence
Calorimeter module

Performance



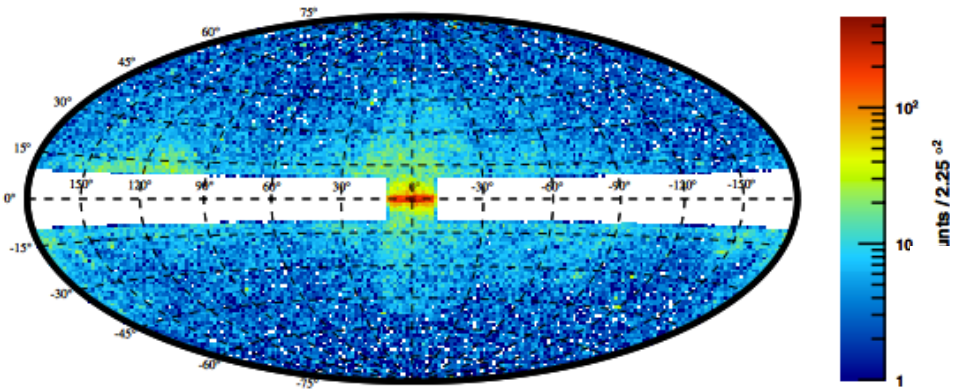


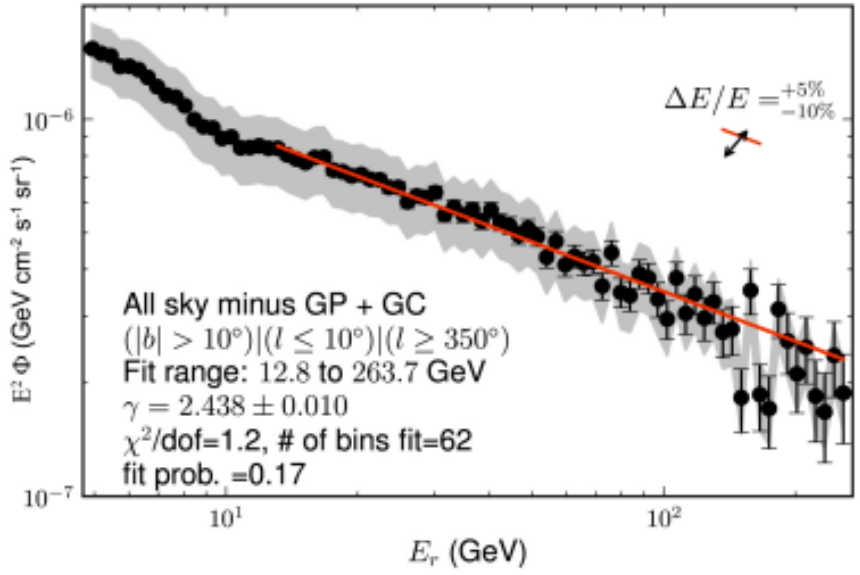
For true photon energy of 130 GeV

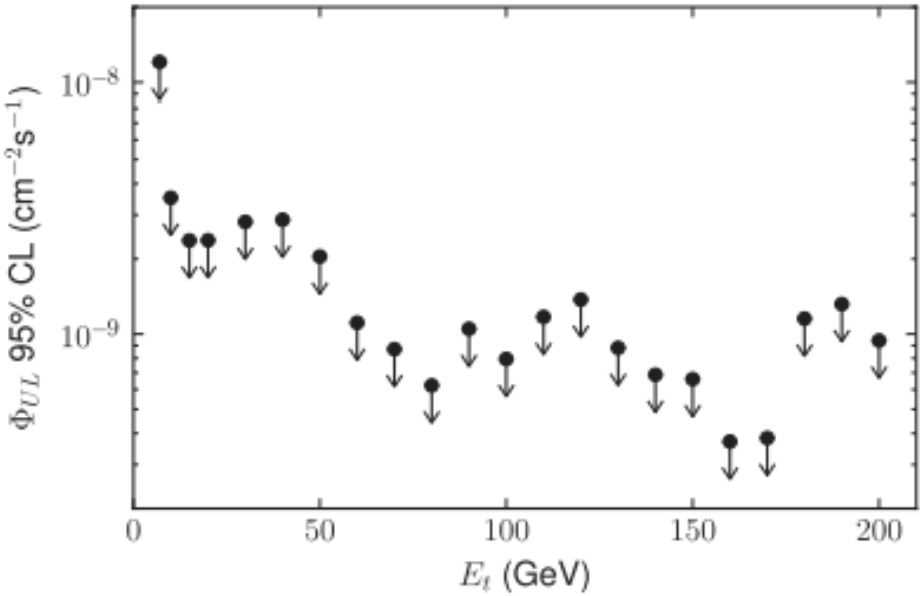
Outline

I. Introduction
II. The line
III. One line or two?
IV. No continuum
V. Instrumental studies
VI. Source of the photons

Fermi results

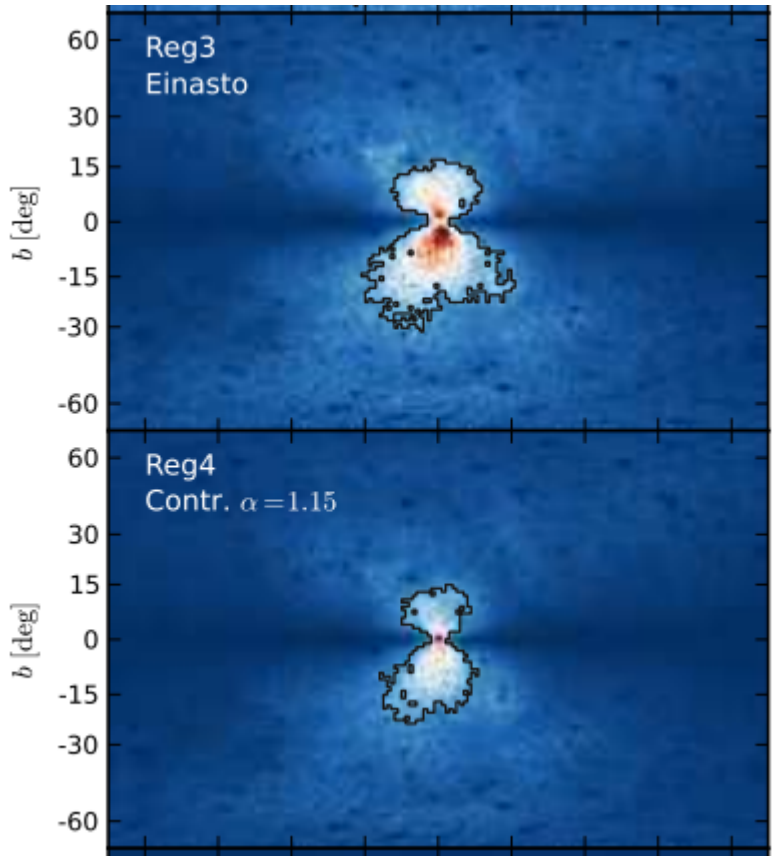






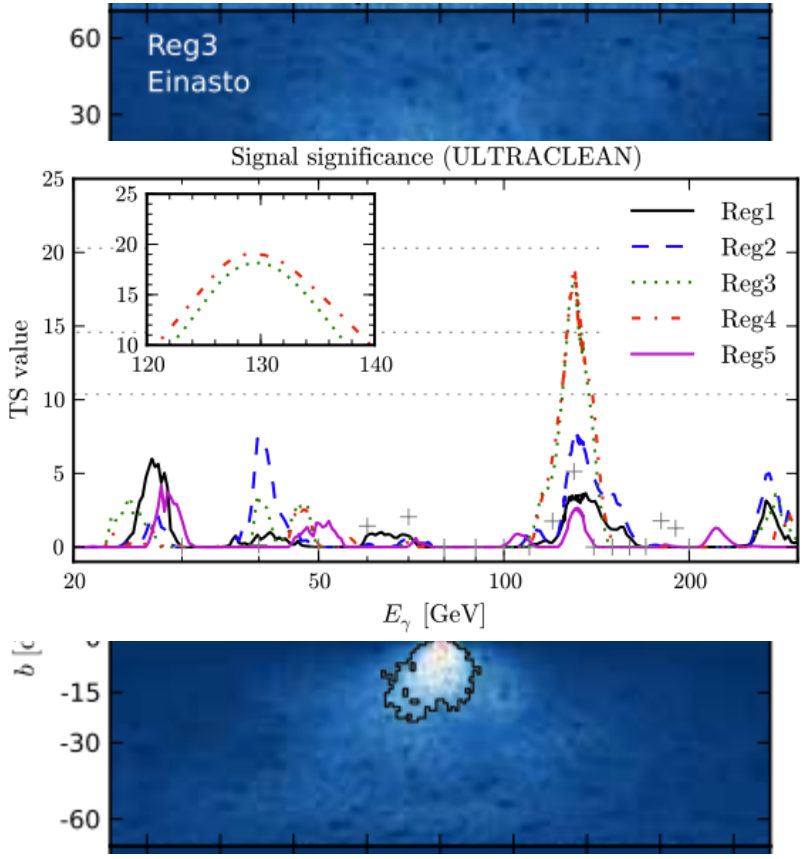
FermiLAT
1205.2739
May 2012

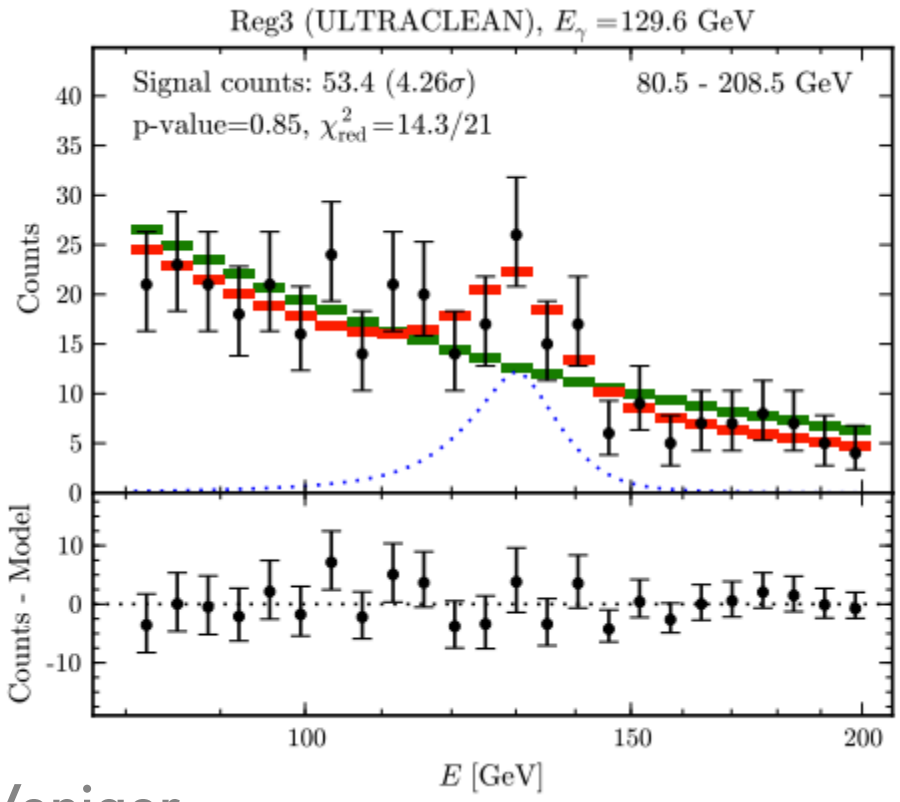
The line



Weniger
1204.2797
May 2012

The line





Weniger
1204.2797
May 2012

HEP **124** records found 1 - 25 ▸ ▸▸ jump to record: 1 Search took 0.02 seconds.

1. **Electroweak Baryogenesis And The Fermi Gamma-Ray Line**
   Jonathan Kozaczuk, Stefano Profumo, Carroll L. Wainwright. N/A. 33 pp.
   e-Print: **arXiv:1302.4781** **[hep-ph]** | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record

2. **On the importance of loop-induced spin-independent interactions for dark matter direct detection**
   Ulrich Haisch, Felix Kahlhoefer. N/A. 18 pp.
   OUTP-13-06P
   e-Print: **arXiv:1302.4454** **[hep-ph]** | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record

3. **Towards the origin?**
   Daniel Treille (Zurich, ETH). 32 pp.
   CERN-OPEN-2012-026
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   CERN Document Server ; Link to Fulltext
   Detailed record

4. **A two-loop Radiative Seesaw with multi-component Dark Matter explaining the possible gamma Excess in the Higgs decay and at the Fermi LAT**
   Mayumi Aoki, Jisuke Kubo, Hiroshi Takano. N/A. 20 pp.
   KANAZAWA-13-02
   e-Print: **arXiv:1302.3936** **[hep-ph]** | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record

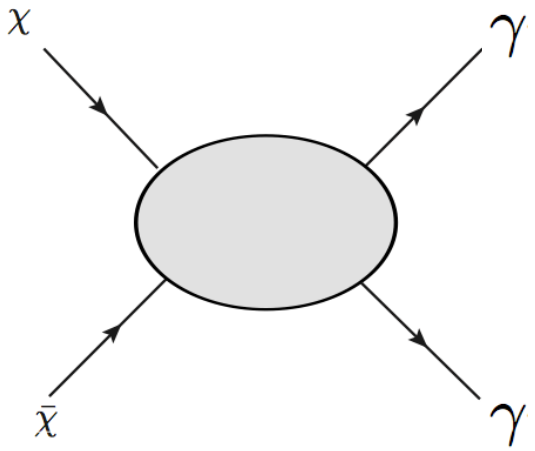
5. **Gamma-ray lines and One-Loop Continuum from s-channel Dark Matter Annihilations**
   C.B. Jackson, Geraldine Servant, Gabe Shaughnessy, Tim M. P. Tait, Marco Taoso. N/A. 32 pp.
   e-Print: **arXiv:1302.1802** **[hep-ph]** | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record

6. **Searching for Spurious Solar and Sky Lines in the Fermi-LAT Spectrum**
   Daniel Whiteson. N/A. 7 pp.
   e-Print: arXiv:1302.0427 **[astro-ph.HE]** | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record

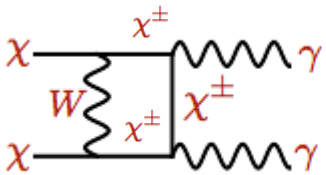
Outline

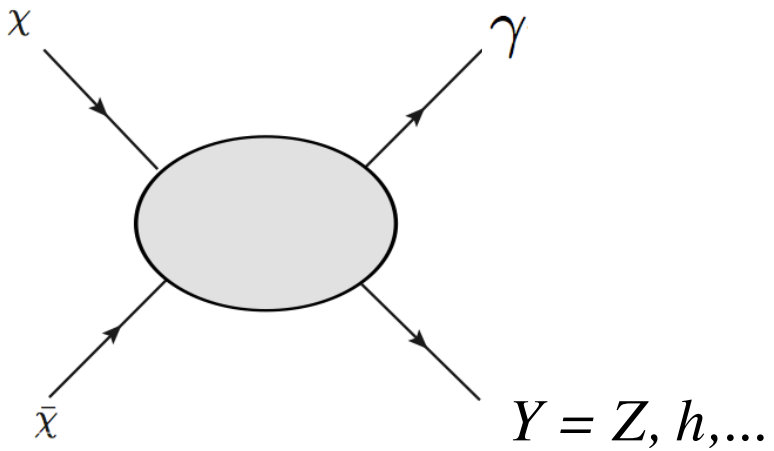
I. Introduction
II. The lines
III. One line or two?
IV. No continuum
V. Instrumental studies
VI. Source of the photons

Lines



Two lines, or not two lines?



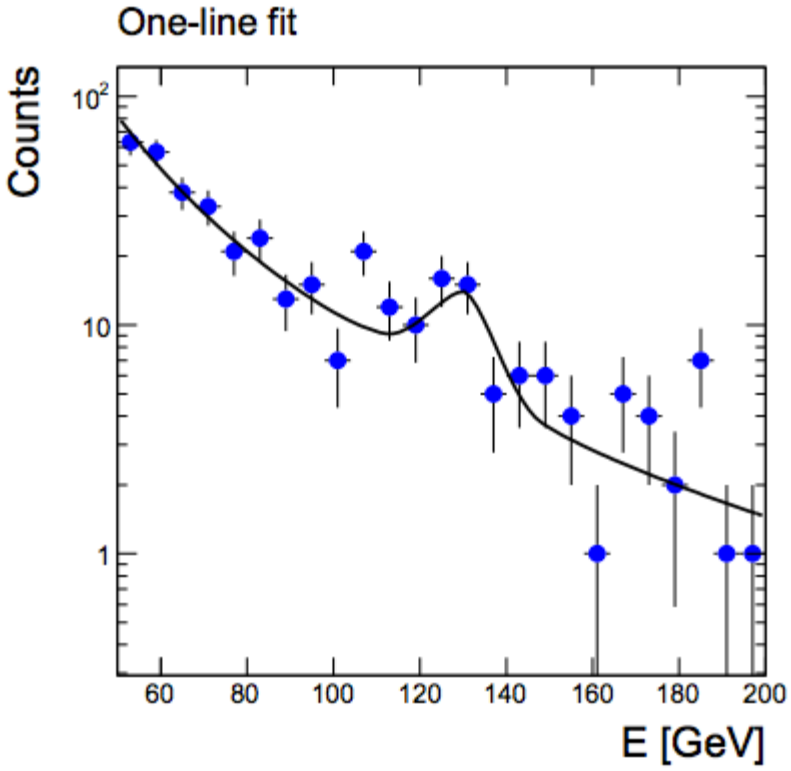


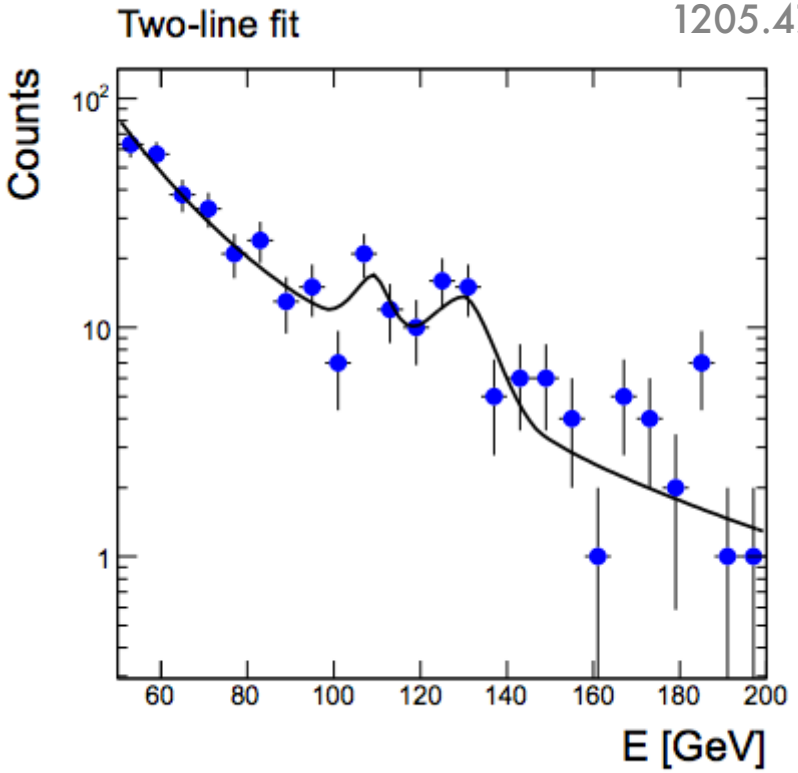
$$E_\gamma = m_\chi \left(1 - \frac{M_Y^2}{4m_\chi^2}\right)$$

Rajaraman, Tait, DW
1205.4723

Lines!

Rajaraman, Tait, DW
1205.4723





$m_X = 130$
$E_\Upsilon = 130$ ($\Upsilon\Upsilon$)

$m_X = 145$
$E_\Upsilon = 130$ (ΥZ)

$m_X = 130$
$E_\Upsilon = 110$ (ΥZ)
$E_\Upsilon = 130$ ($\Upsilon\Upsilon$)

Fun with titles

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Two lines or not two lines? That is the question of gamma ray spectra

Arvind Rajaraman, Tim M.P. Tait and Daniel Whiteson

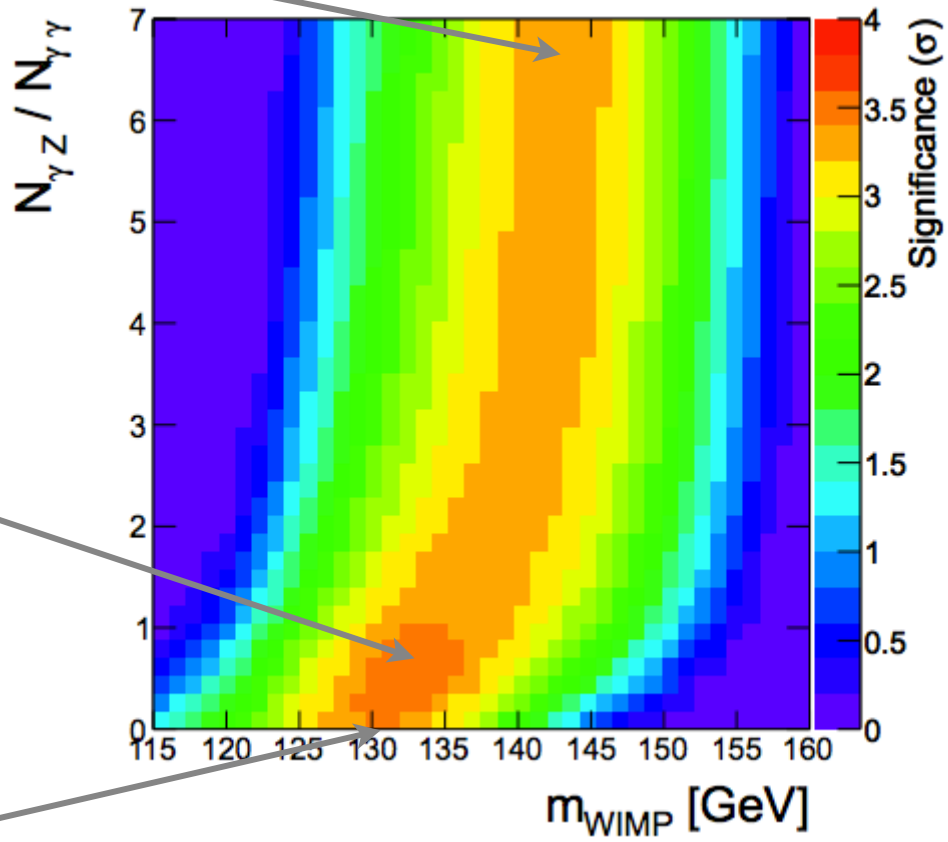
Rajaraman, Tait, DW
1205.4723

Analysis

$m_x = 145$
$E_\gamma = 130$ (γZ)

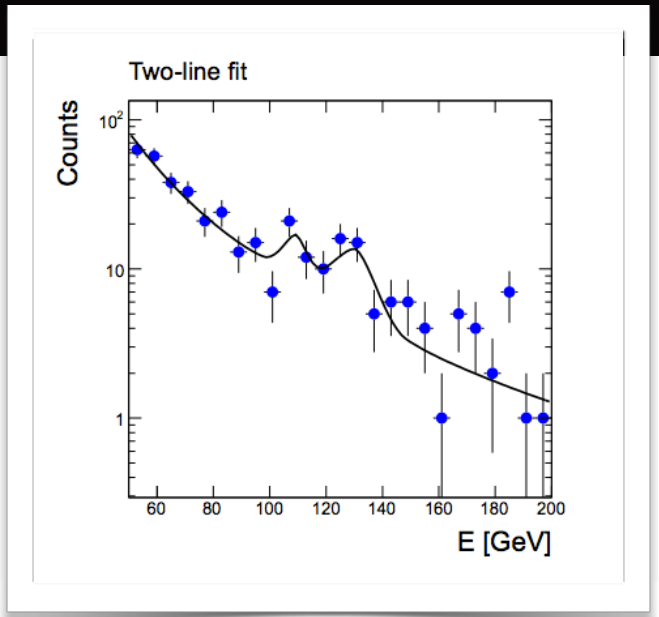
$m_x = 130$
$E_\gamma = 110$ (γZ)
$E_\gamma = 130$ ($\gamma\gamma$)

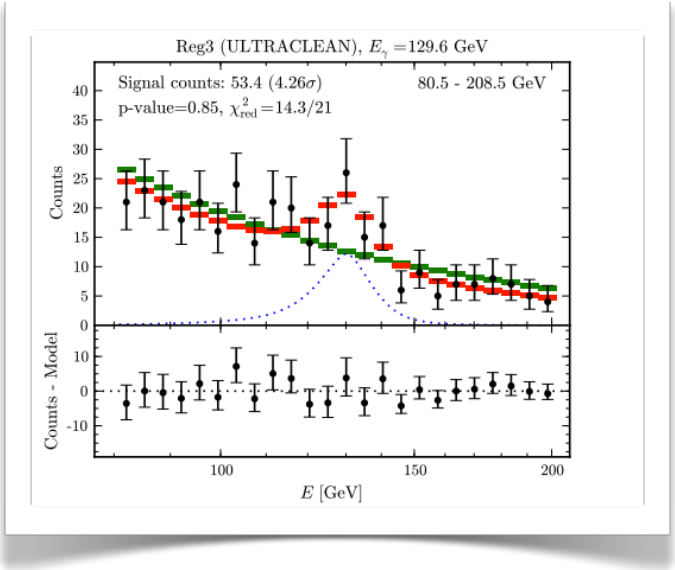
$m_x = 130$
$E_\gamma = 130$ ($\gamma\gamma$)

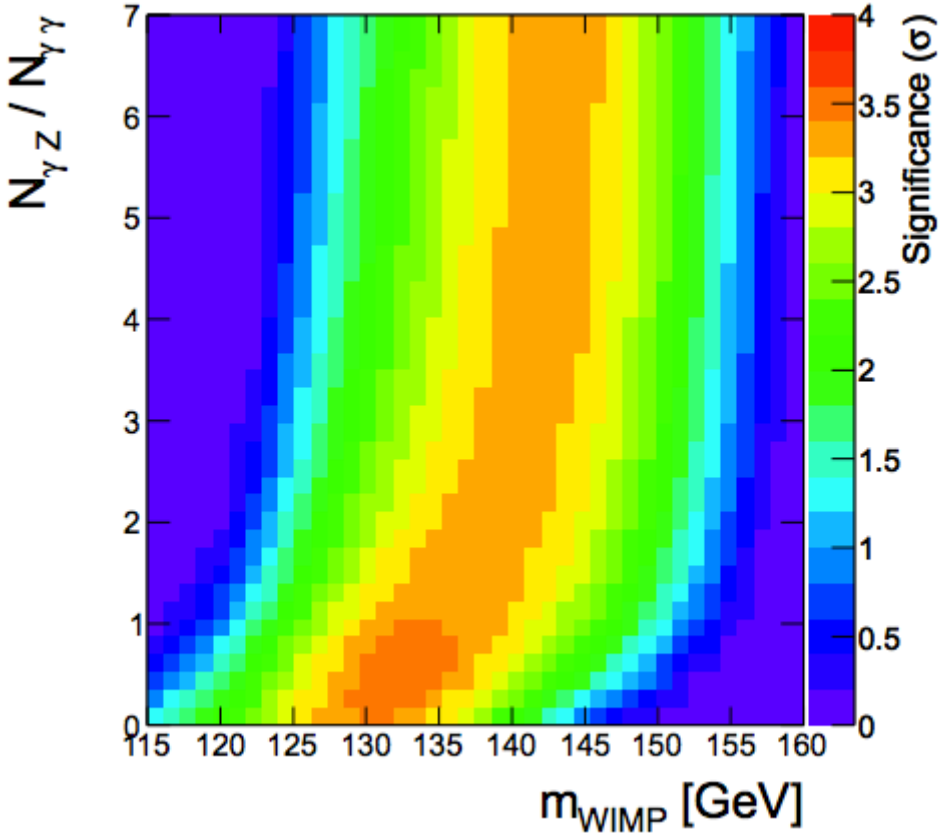


Rajaraman, Tait, DW
1205.4723

Analysis







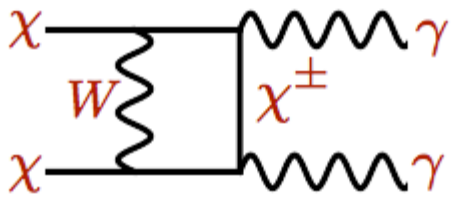
Rajaraman, Tait, DW
1205.4723

Outline

I. Introduction
II. The lines
III. One line or two?
IV. No continuum
V. Instrumental studies
VI. Source of the photons

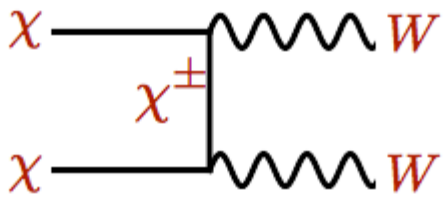
Processes

Monochromatic Photons



Direct decay to photons,
a line in photon energy spectrum

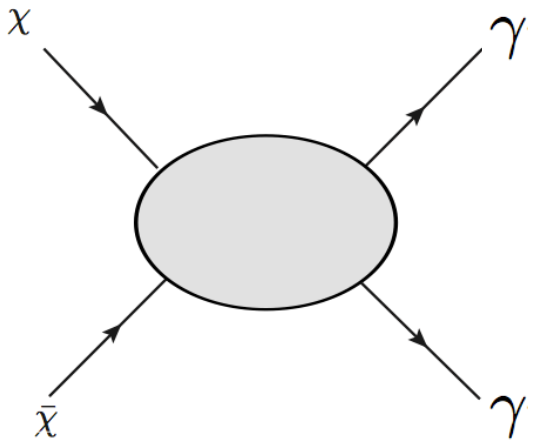
Continuum Photons



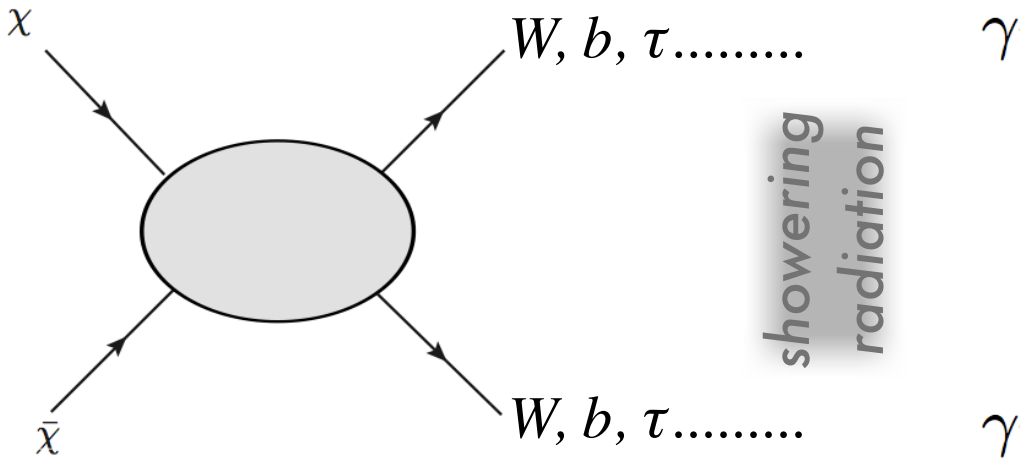
Annihilation to SM final states that
shower into photons

Lisanti, IDM2012

Processes

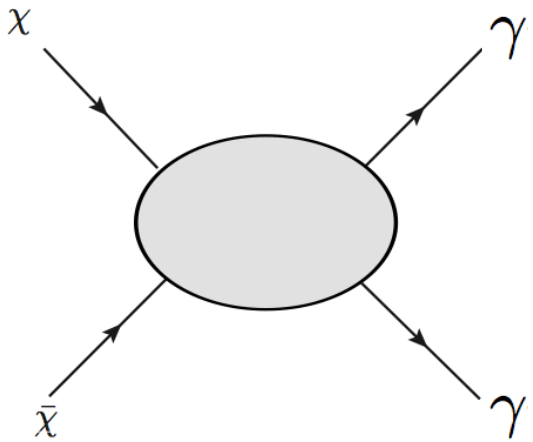


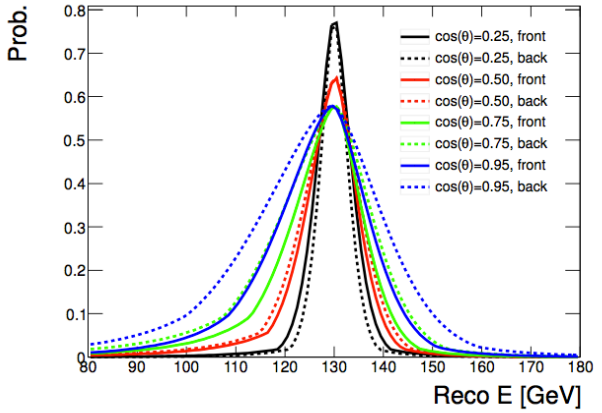
Line feature

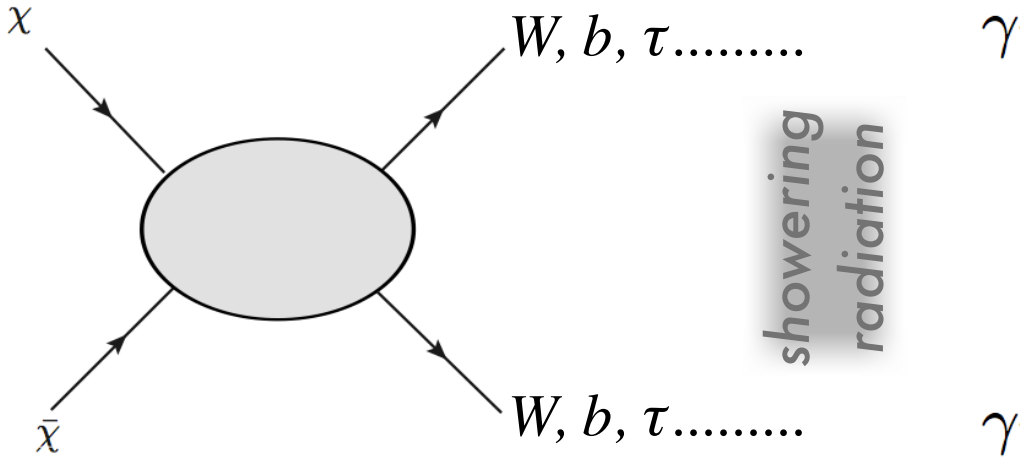


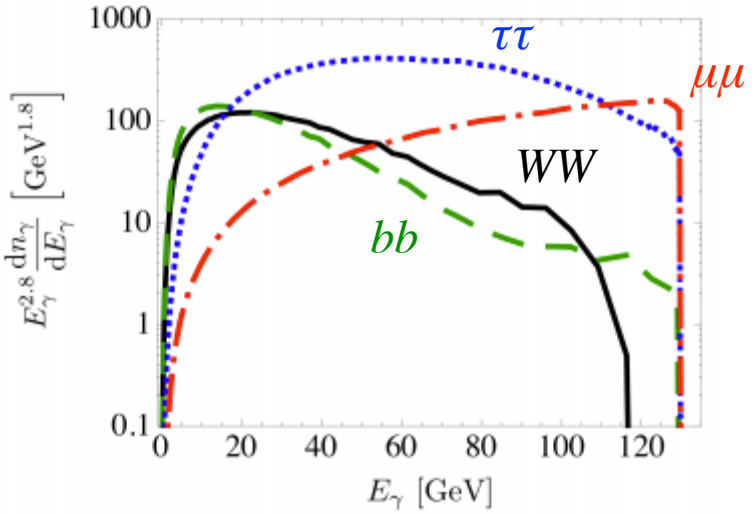
Broad spectrum

Processes



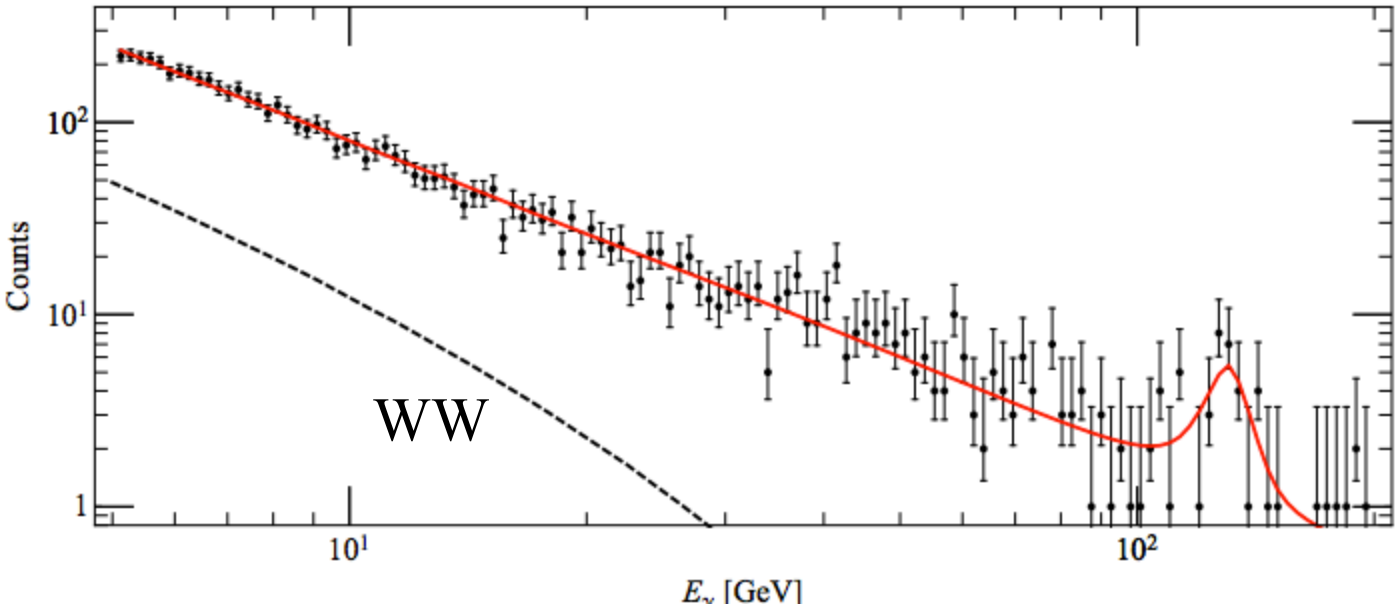






Cohen et al 1207.0800

Continuum



Cohen et al
1207.0800

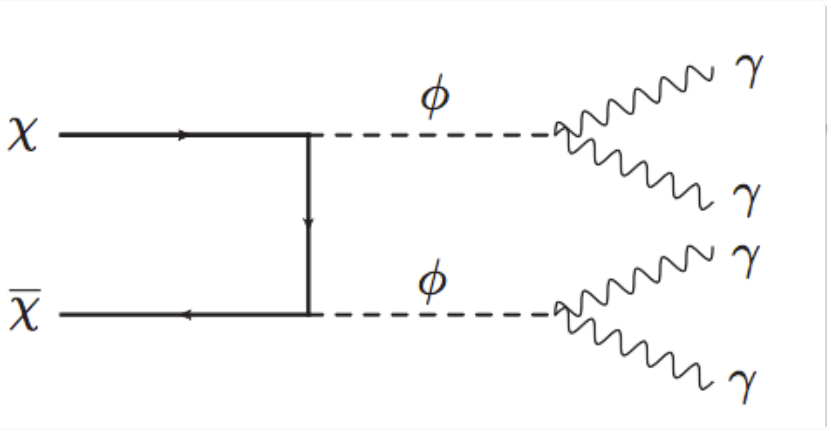
Three Exceptions for Thermal Dark Matter with Enhanced Annihilation to $\gamma\gamma$

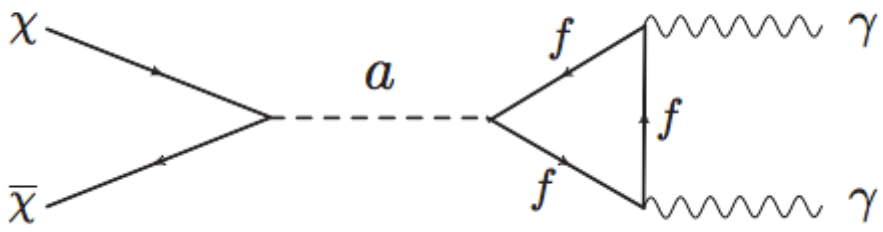
Sean Tulin, Hai-Bo Yu, and Kathryn M. Zurek
Department of Physics, University of Michigan, Ann Arbor, MI 48109
(Dated: August 10, 2012)

Recently, there have been hints for dark matter (DM) annihilation in the galactic center to one or more photon

Gamma Lines without a Continuum:
Thermal Models for the Fermi-LAT 130 GeV Gamma Line

Yang Bai[a,b] and Jessie Shelton[c]

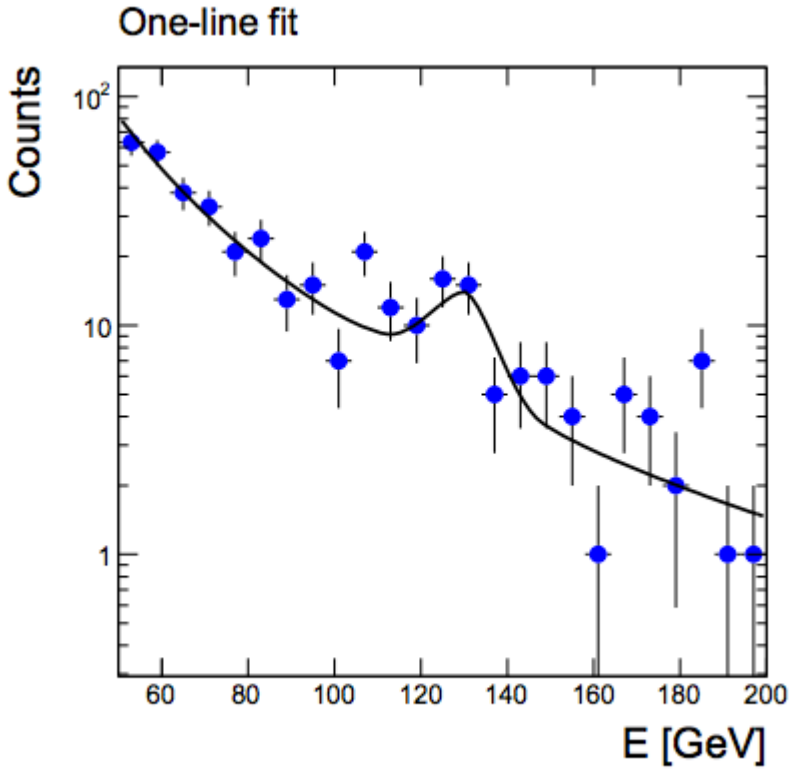




Outline

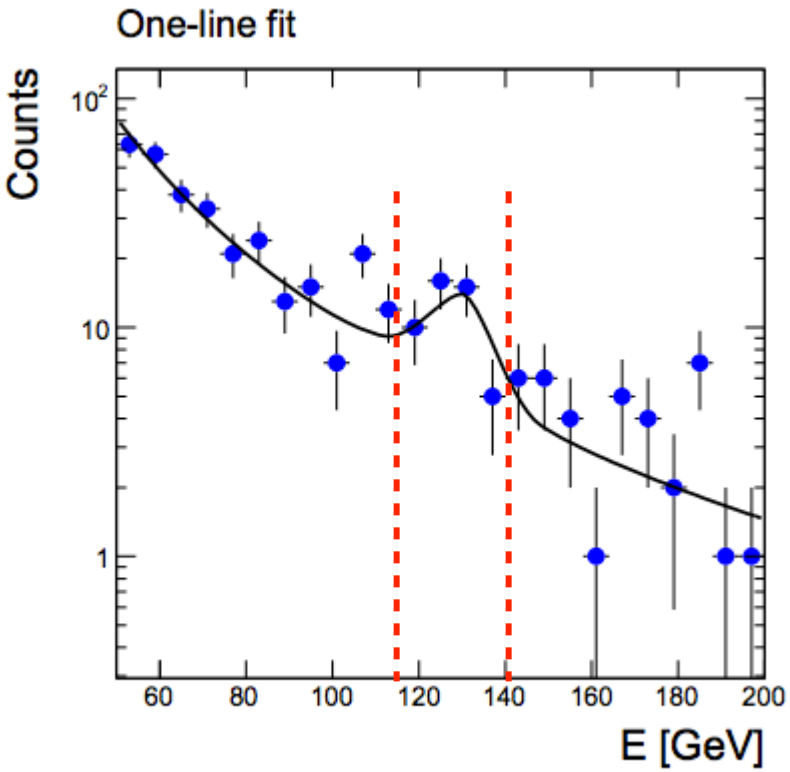
I. Introduction
II. The lines
III. One line or two?
IV. No continuum
V. Instrumental studies
VI. Source of the photons

photons



Could the peak photons be spurious?
Are they different in some way?

First idea



<u>isolate signal photons</u>

Use energy cut

<u>But</u>

S/B is not large.

Few signal photons.

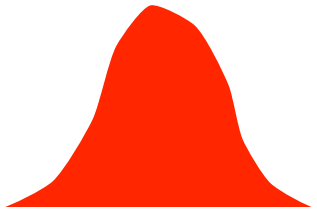
Can we do better?

sPlots

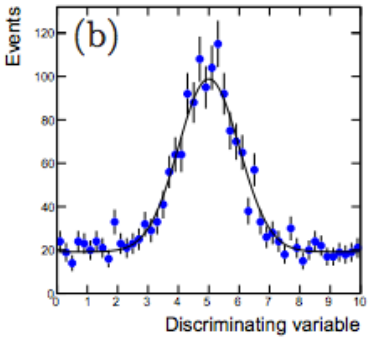
discriminating variable

background

signal



data



sPlots

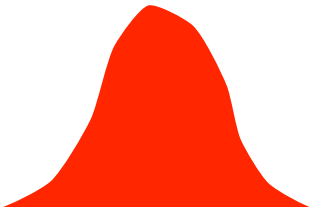
(pdfs factorize)

discriminating variable

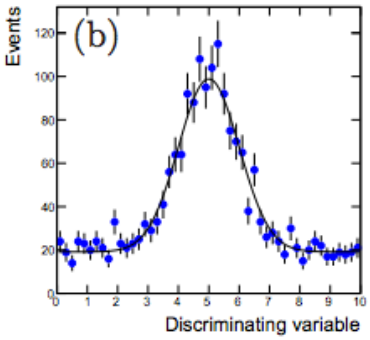
unfolding variable

background

signal



data



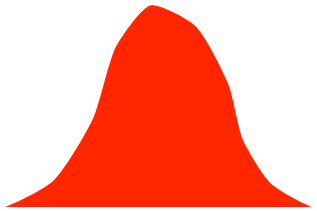
sPlots

(pdfs factorize)

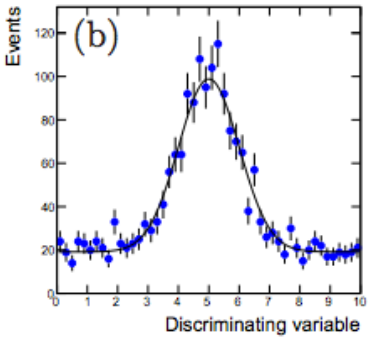
discriminating variable

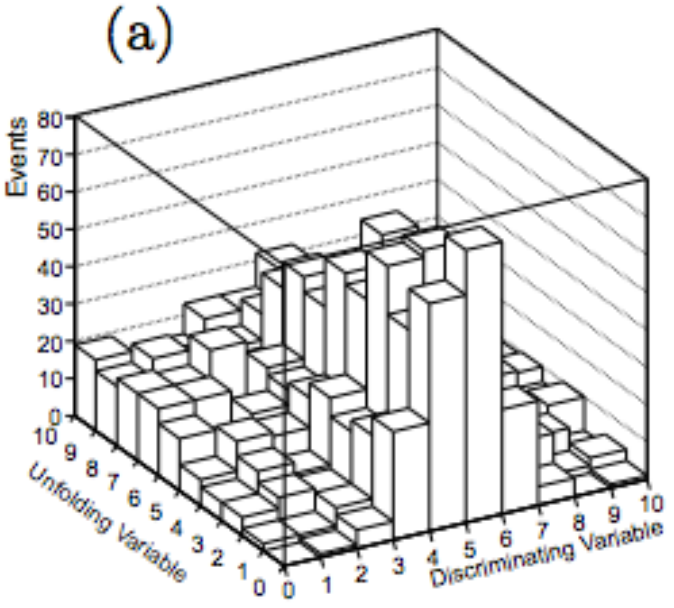
background

signal



data





sPlots

Given pdfs for two sources $f_1(y)$, and $f_2(y)$ in the discriminating variable y, one can construct a histogram in another unfolding variable x using weights for each source class, sP_1 and sP_2, defined as:

$$sP_1(y) = \frac{\mathbf{V}_{11} f_1(y) + \mathbf{V}_{12} f_2(y)}{N_1 f_1(y) + N_2 f_2(y)}$$

$$sP_2(y) = \frac{\mathbf{V}_{21} f_1(y) + \mathbf{V}_{22} f_2(y)}{N_1 f_1(y) + N_2 f_2(y)}$$

where N_1 and N_2 are the number of events in each class, as extracted by a likelihood fit of f_1 and f_2 to the observed distribution in y, and the inverse of the matrix $\mathbf{V}$ is a symmetric 2×2 matrix defined as

$$\mathbf{V}^{-1}_{ab} = \sum_{i=1}^{N} \frac{(N_1 + N_2) f_a(y_i) f_b(y_i)}{(N_1 f_1(y_i) + N_2 f_2(y_i))^2}$$

A histogram h in the unfolding variable x can then be constructed for source 1 as

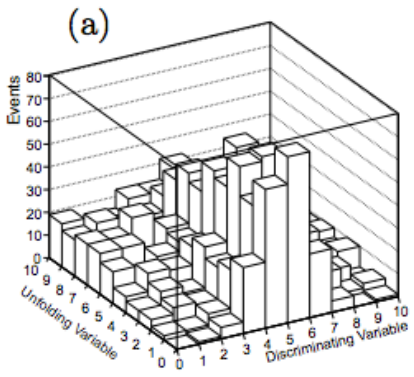
$$h_i = \sum_{j=1}^{N_i} sP_1(y_{ji})$$

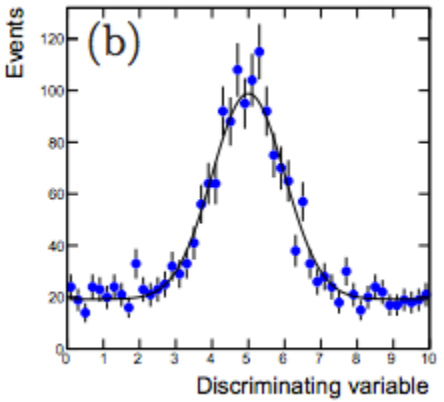
where i is the bin index in the x variable, N_i is the number of events in that bin, and y_{ji} is the value of the y variable for the jth event in the ith bin. A histogram for source 2 would be constructed by replacing $sP_1 \rightarrow sP_2$.

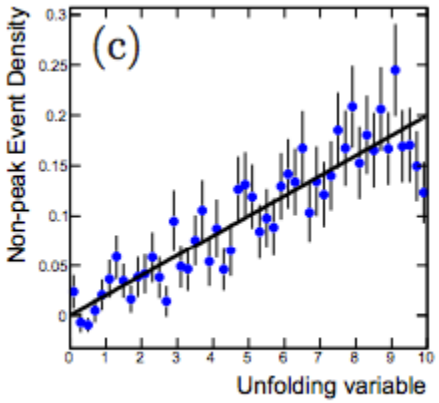
sPlots

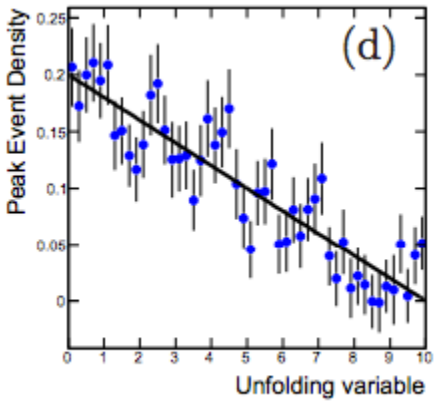
$$f_{\text{peak}}(x,y) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(y-5)^2} \times \frac{10-x}{50}$$

$$f_{\text{non-peak}}(x,y) = \frac{x}{50}$$



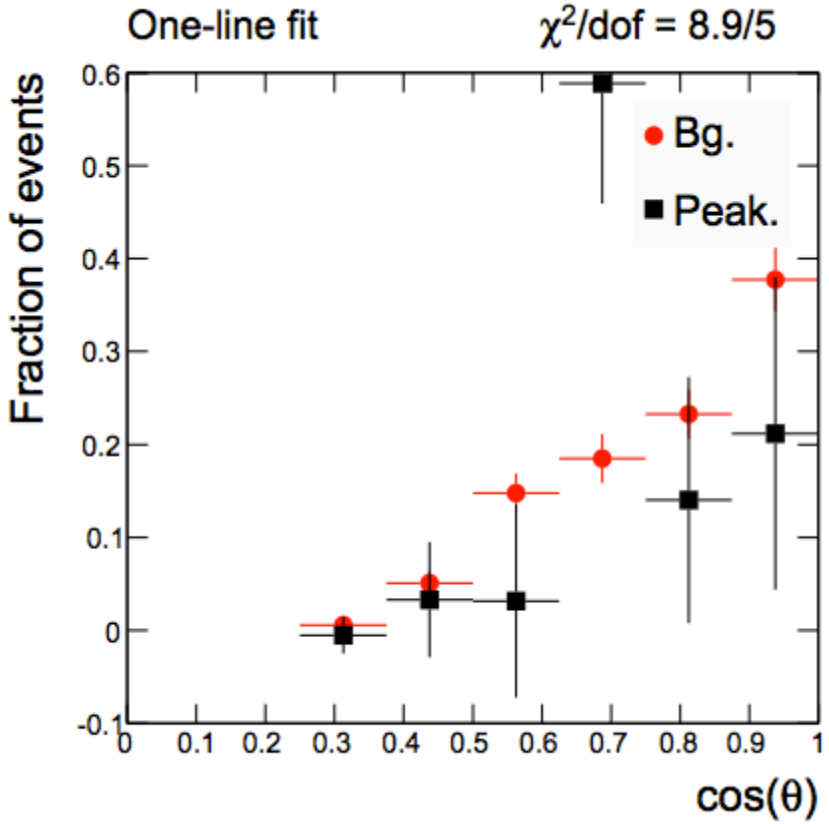


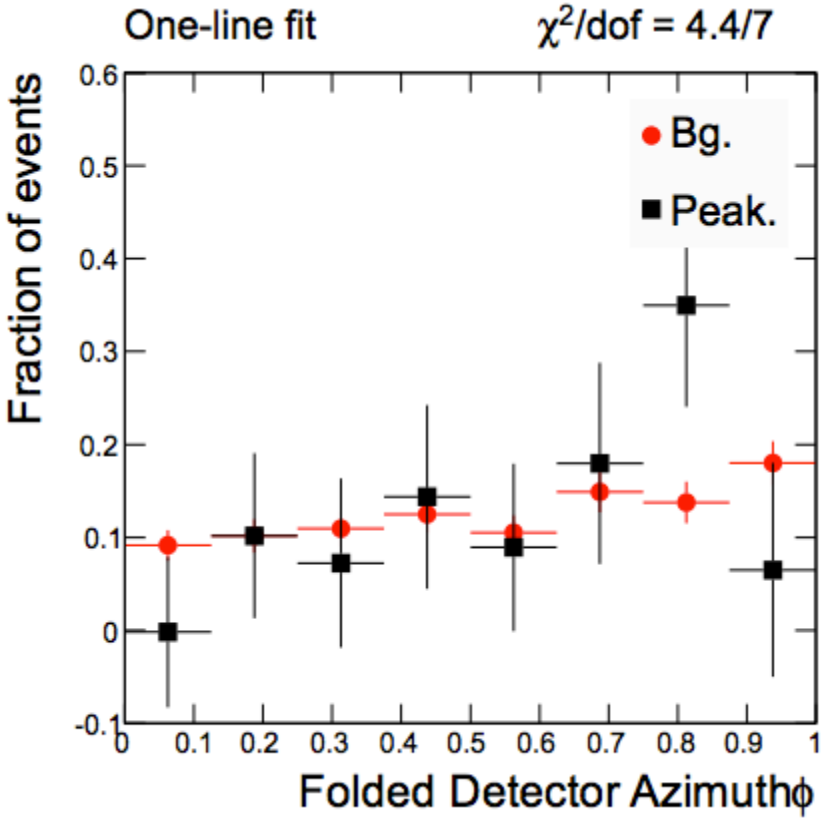




Whiteson
1208.3677

Results



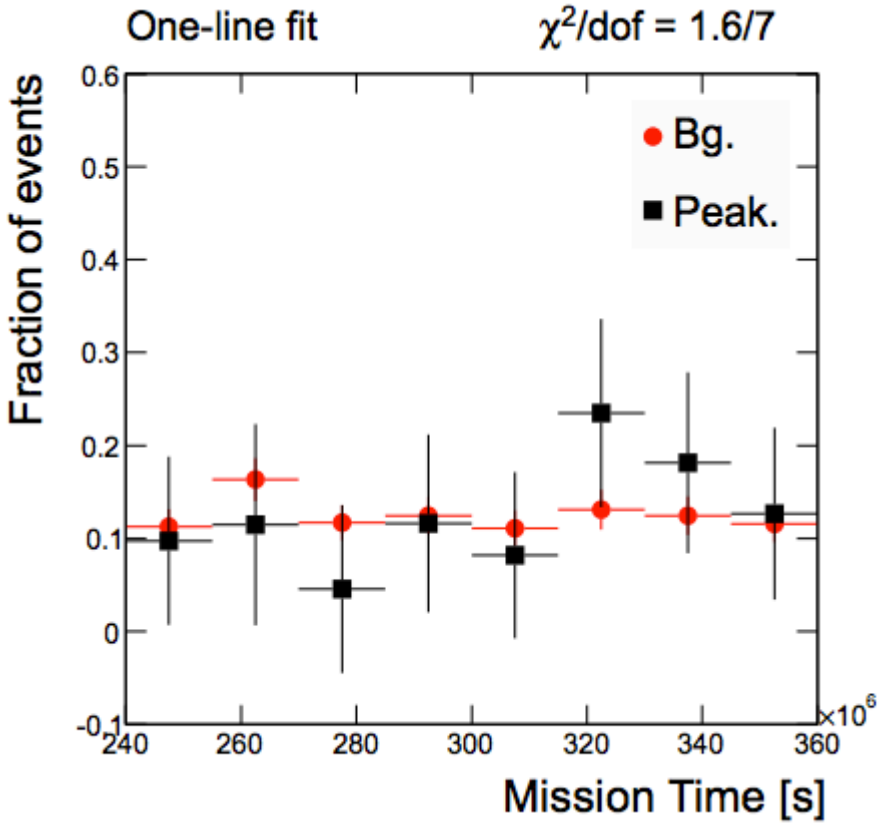


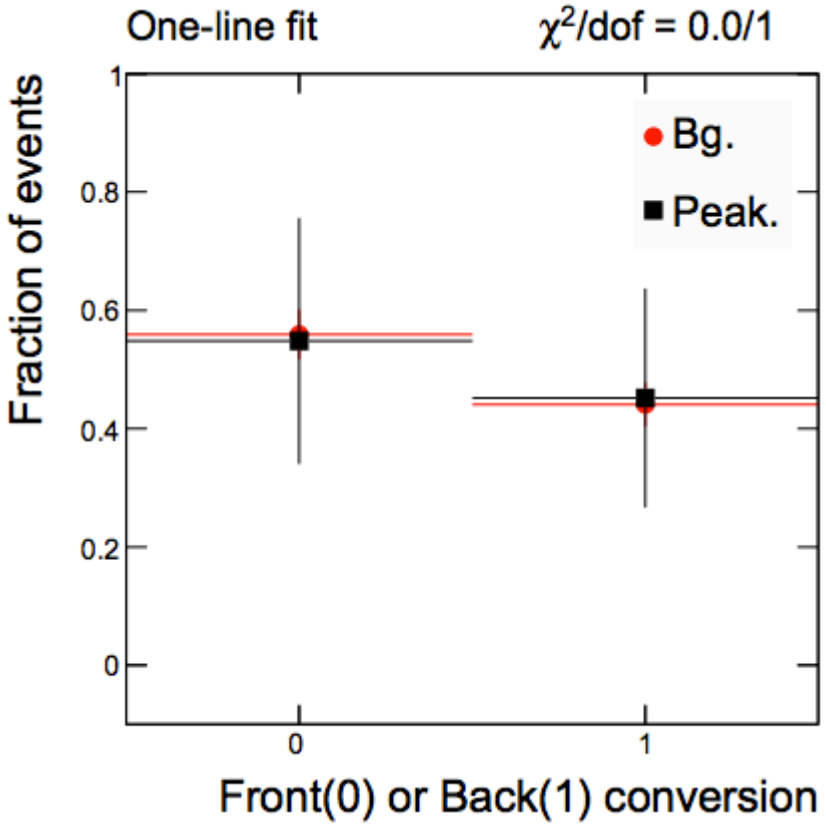
- incident angle θ, measured with respect to the top-face normal of the LAT,

- azimuth angle ϕ, measured with respect to the top-face normal of the LAT, folded as described in Eq. (15) of Ref. [11].

Whiteson
1208.3677

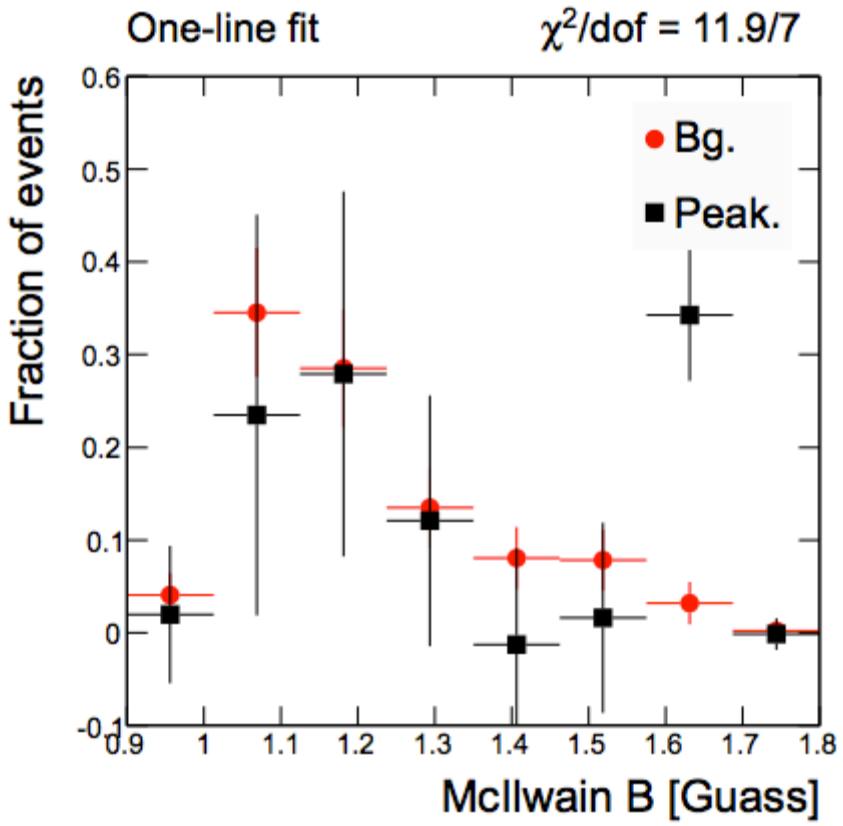
variables

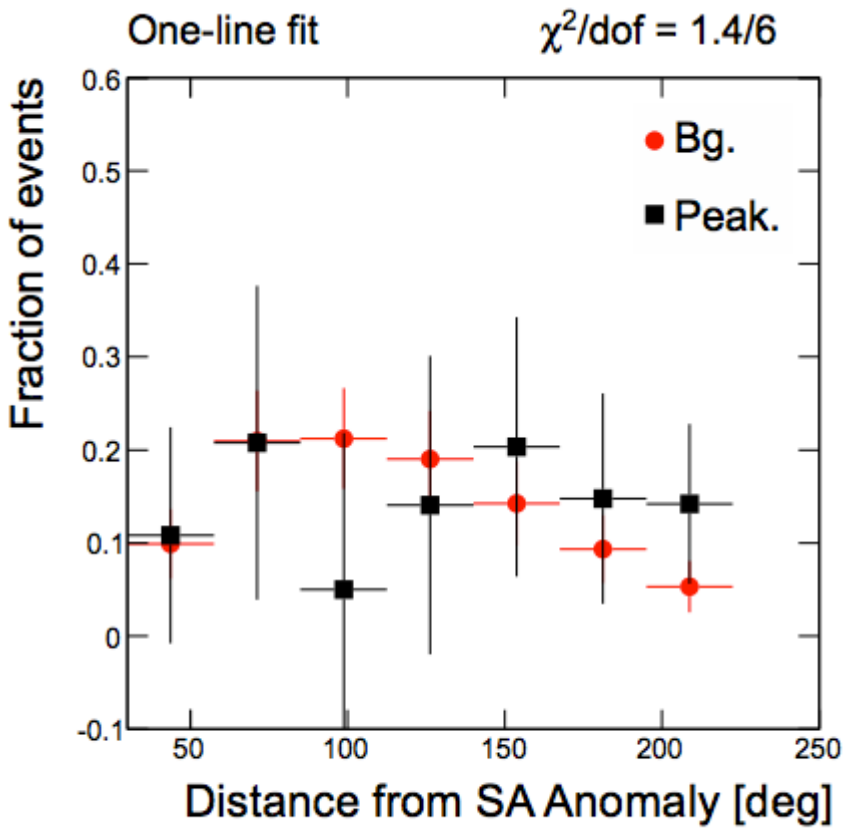




Whiteson
1208.3677

External issues?

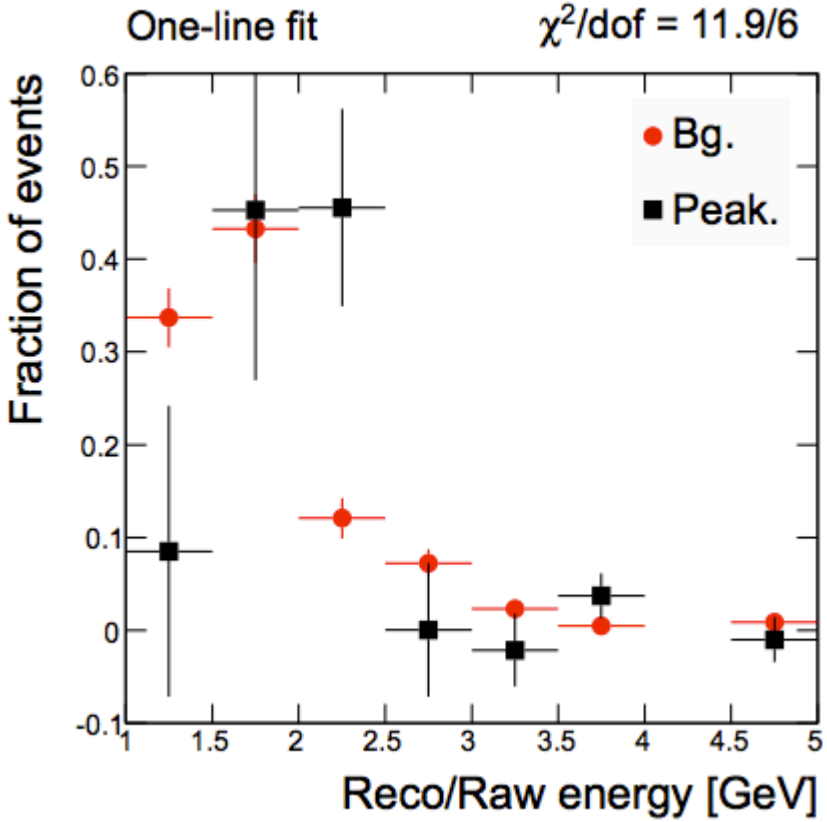


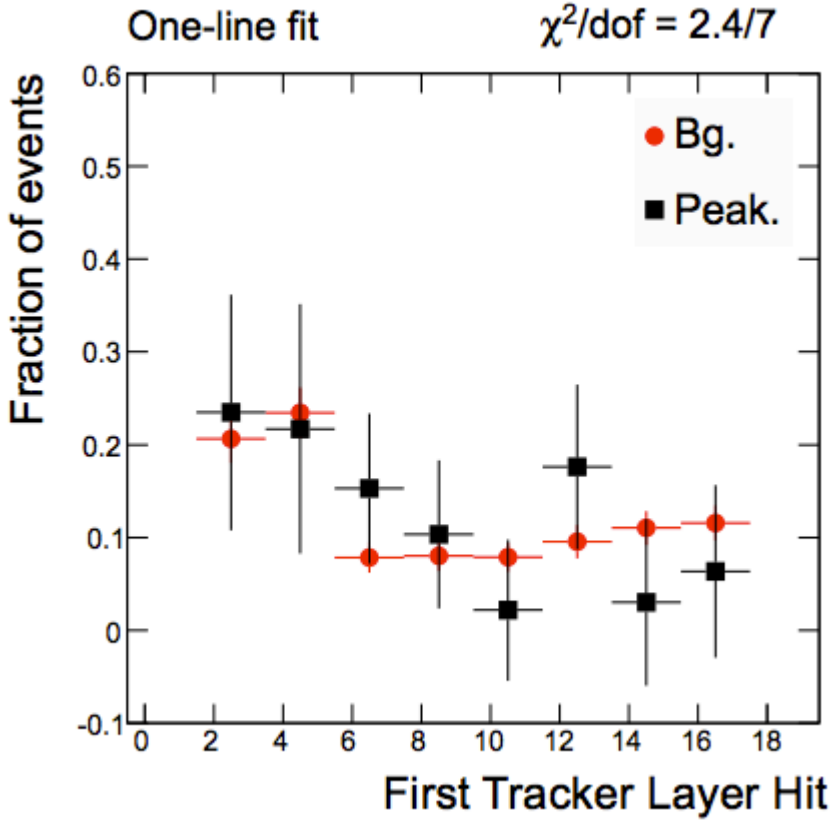


Whiteson 1208.3677

- the magnetic field in which the LAT is immersed, as parameterized by the McIlwain B and L parameters [14],

Reconstruction

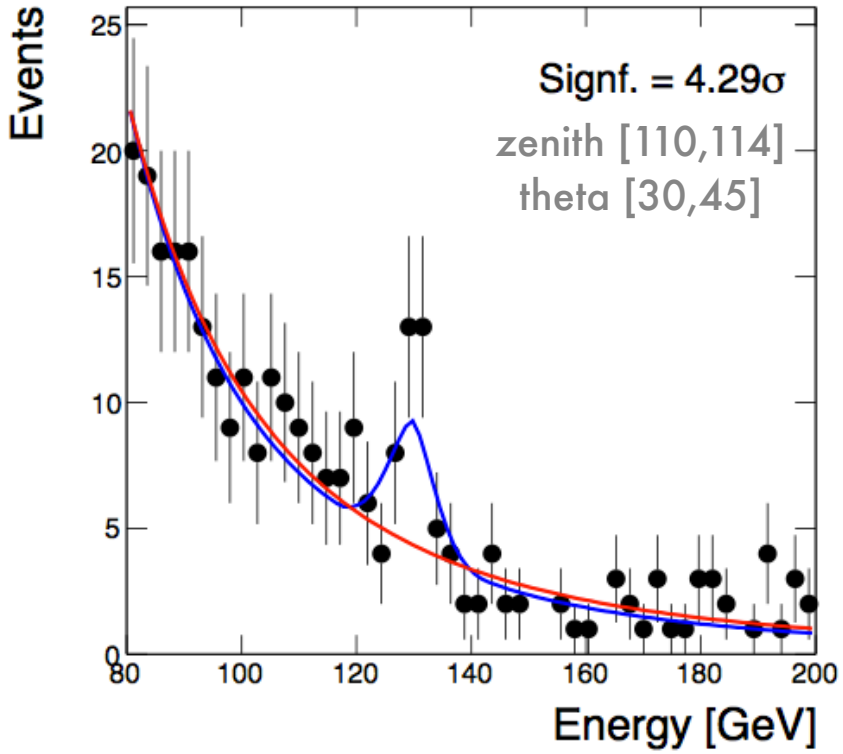


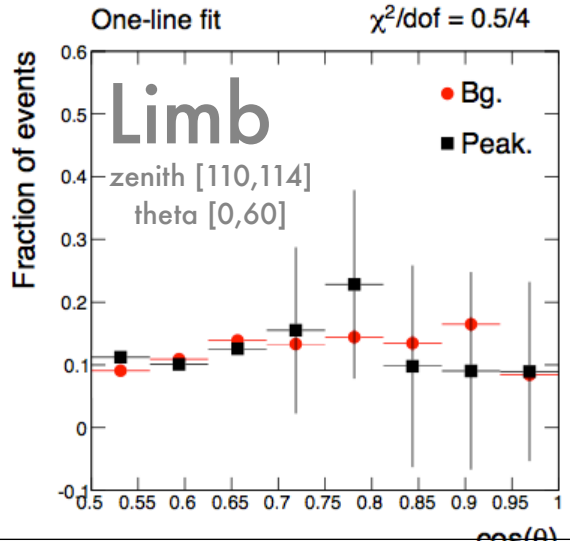


Whiteson
1208.3677

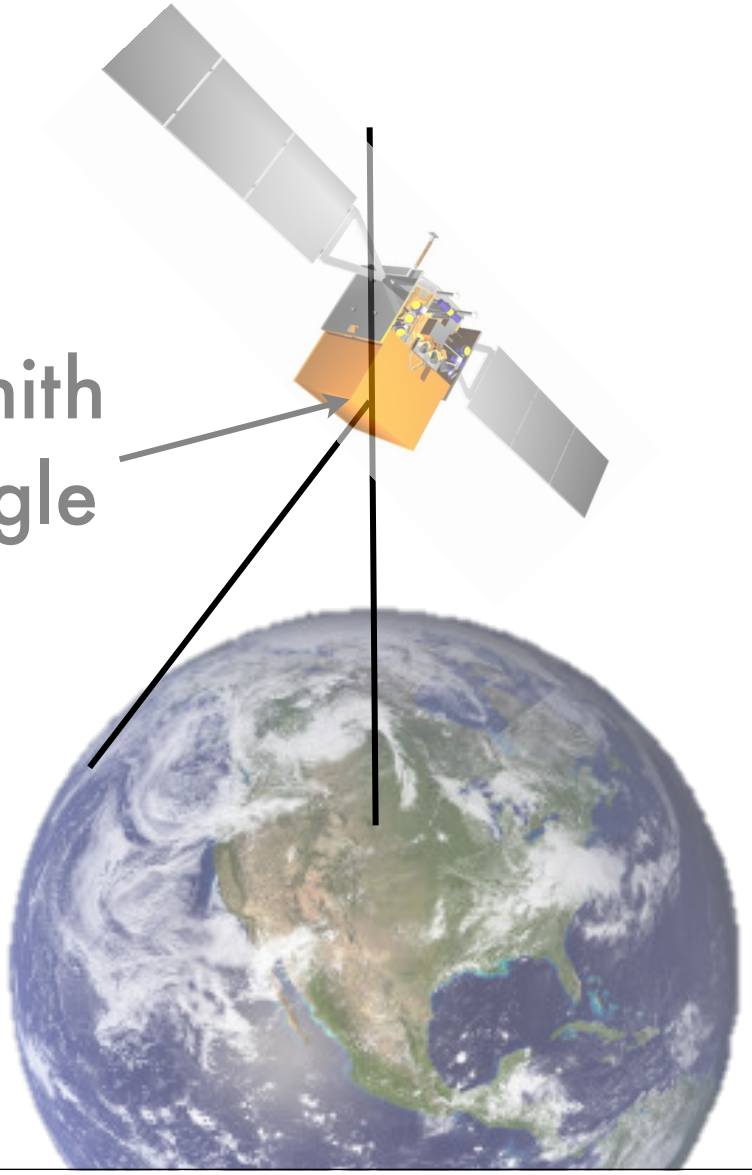
Limb

1st reported:
Finkbiener, et al
1209.4562



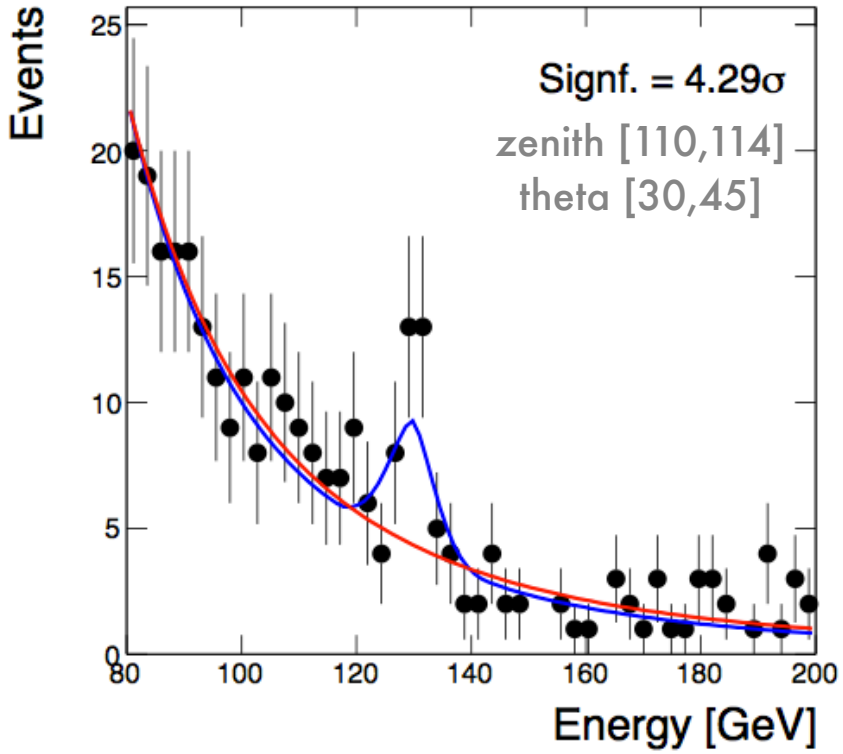


zenith angle

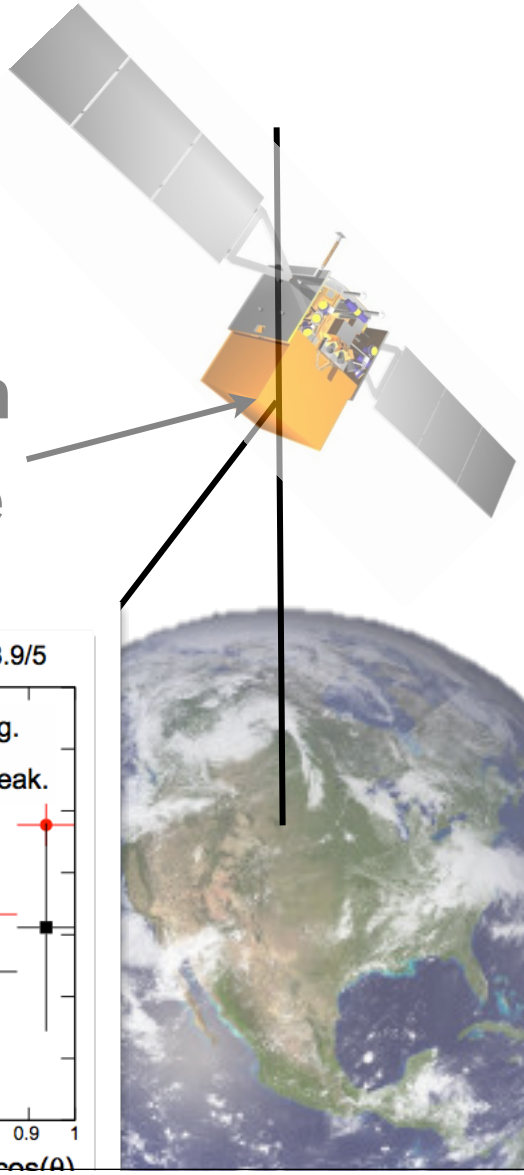


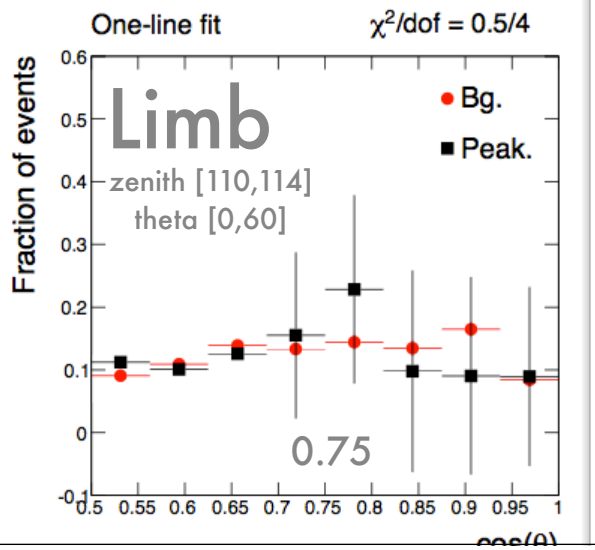
Limb

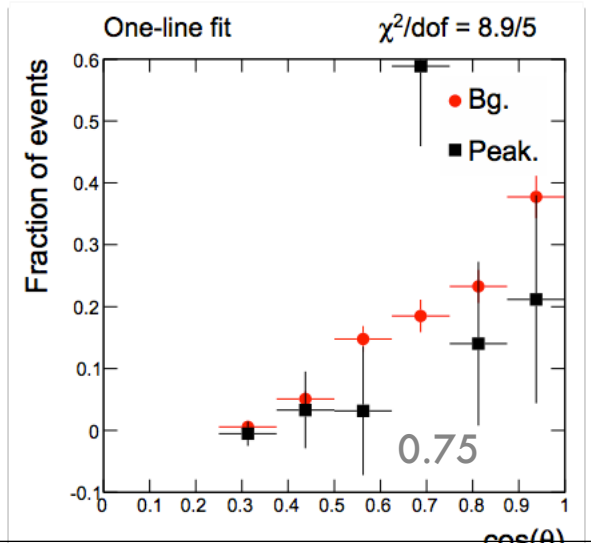
Whiteson
1302.0427



zenith angle





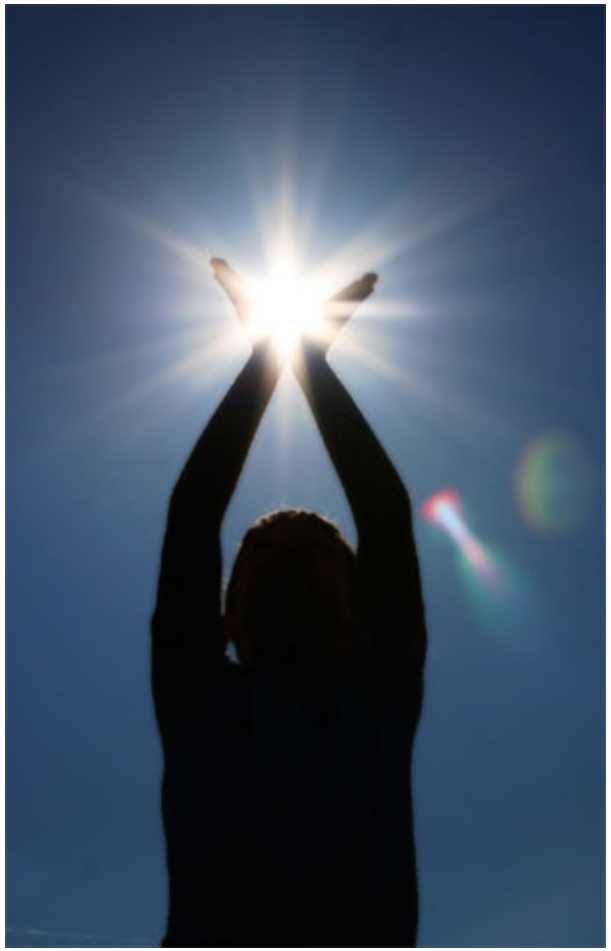


Other sources

Earth's limb is a powerful control region.

Are there other regions?

Other sources

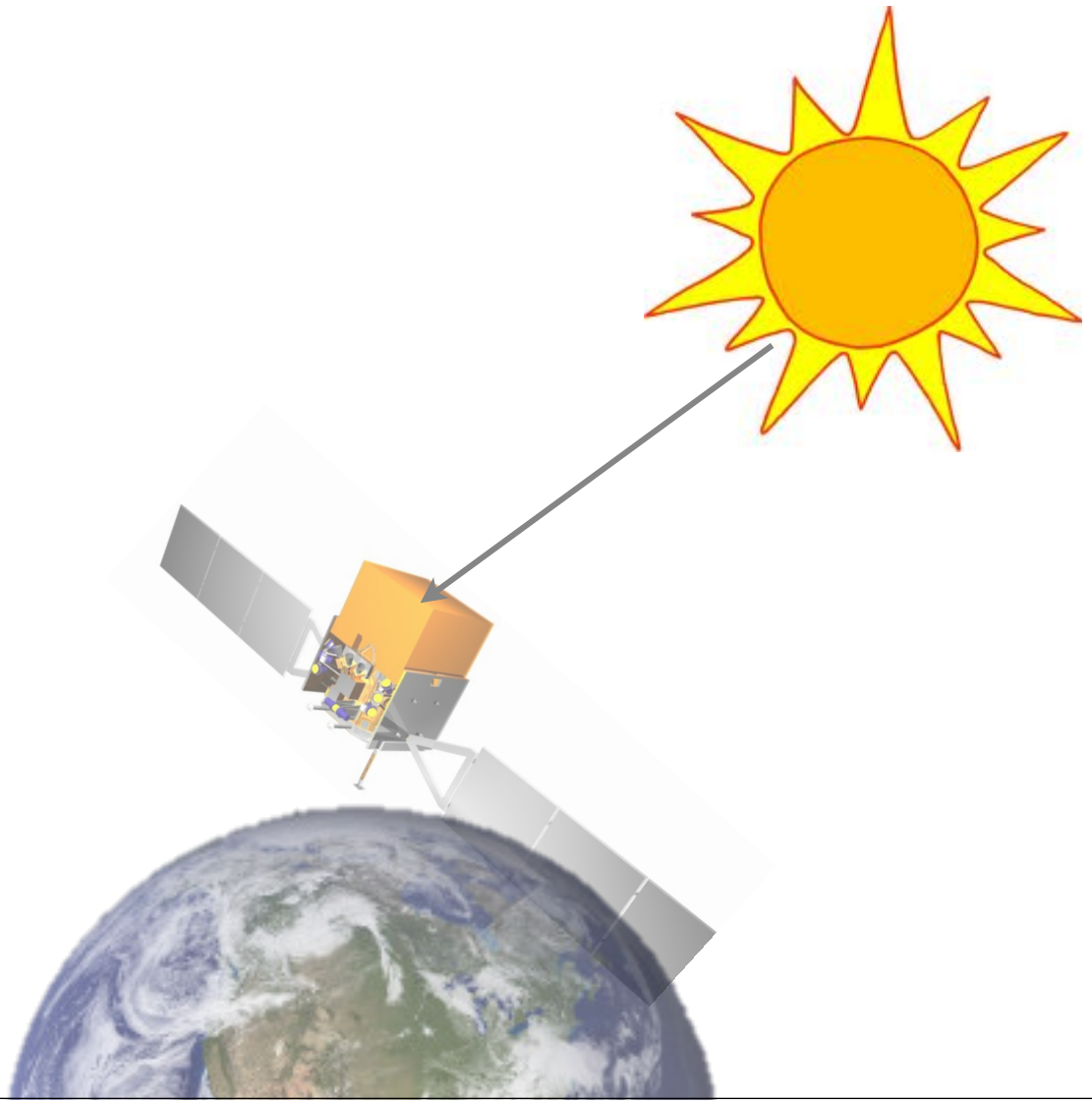


Earth's limb is a powerful control region.

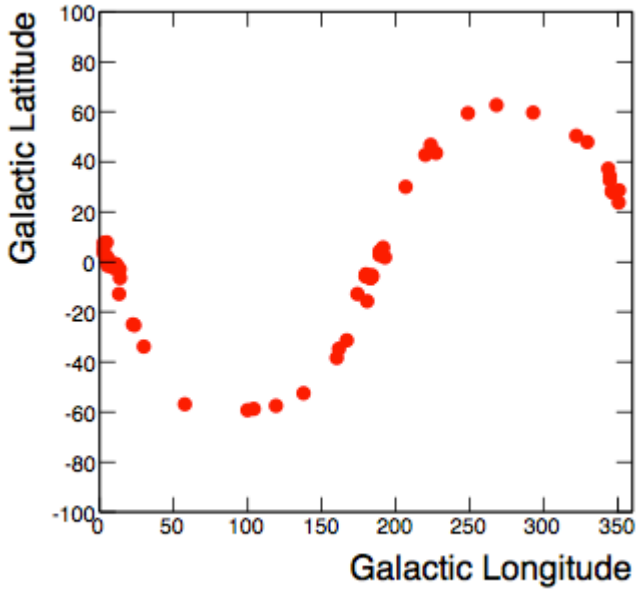
Are there other regions?

The Sun!

Solar region

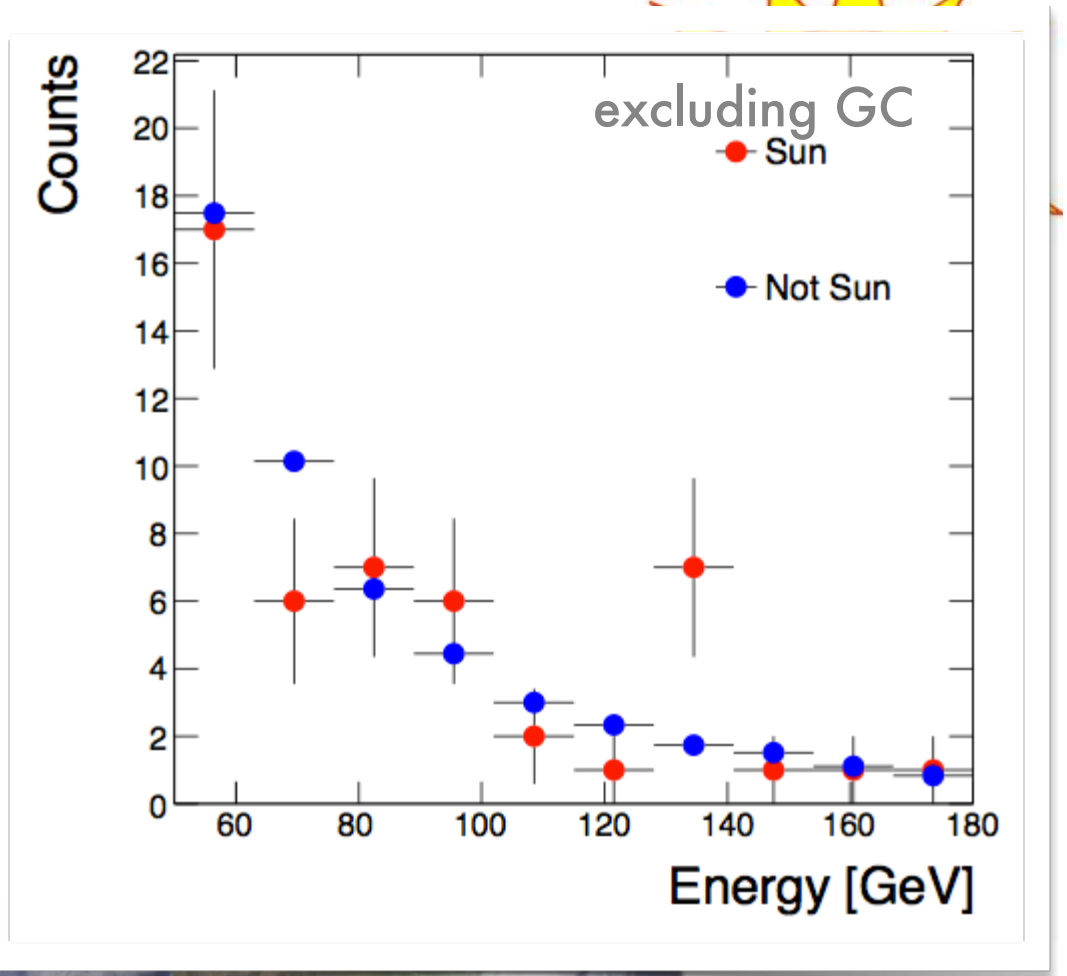


Find galactic coord of solar photons

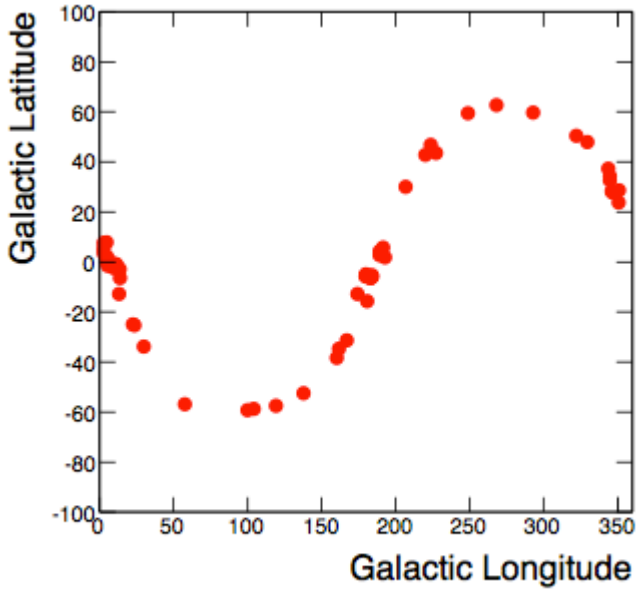


Solar region

Whiteson
1302.0427

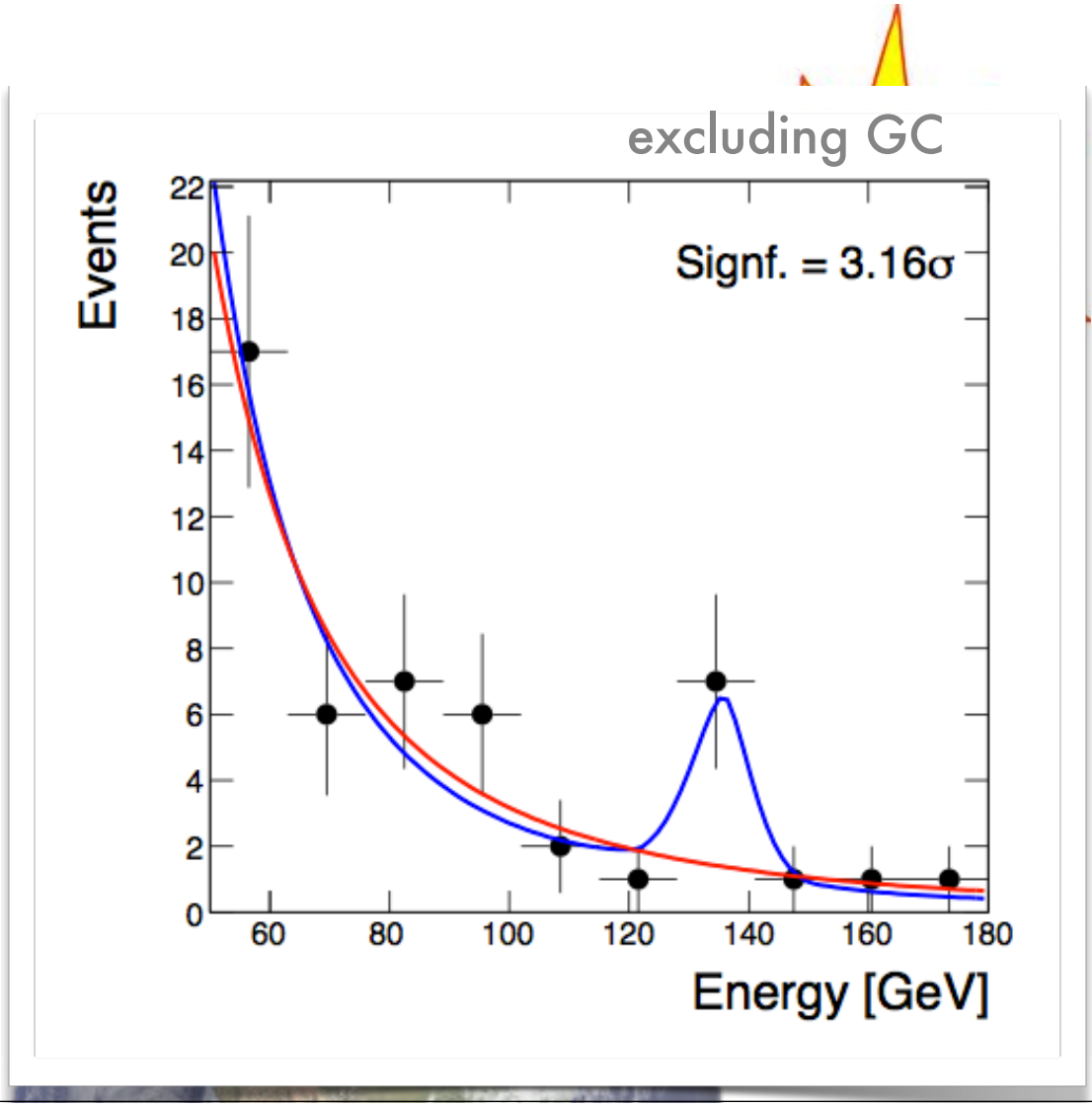


Find galactic coord of solar photons

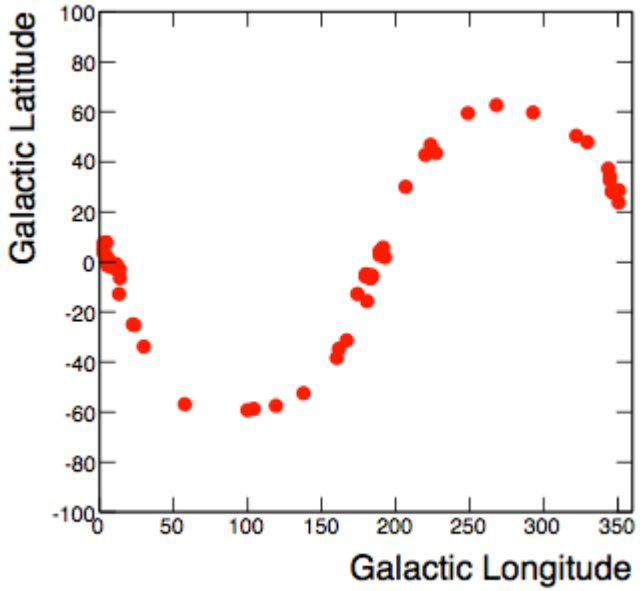


Solar region

Whiteson
1302.0427



Find galactic coord of solar photons



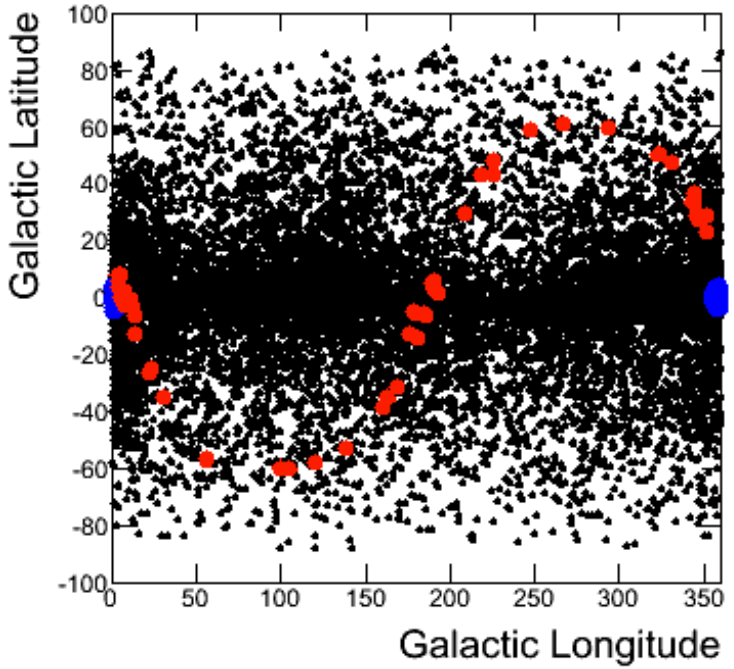
Common features

(1) Find common values of instr. variables across peaks:
GC / Limb / Sun

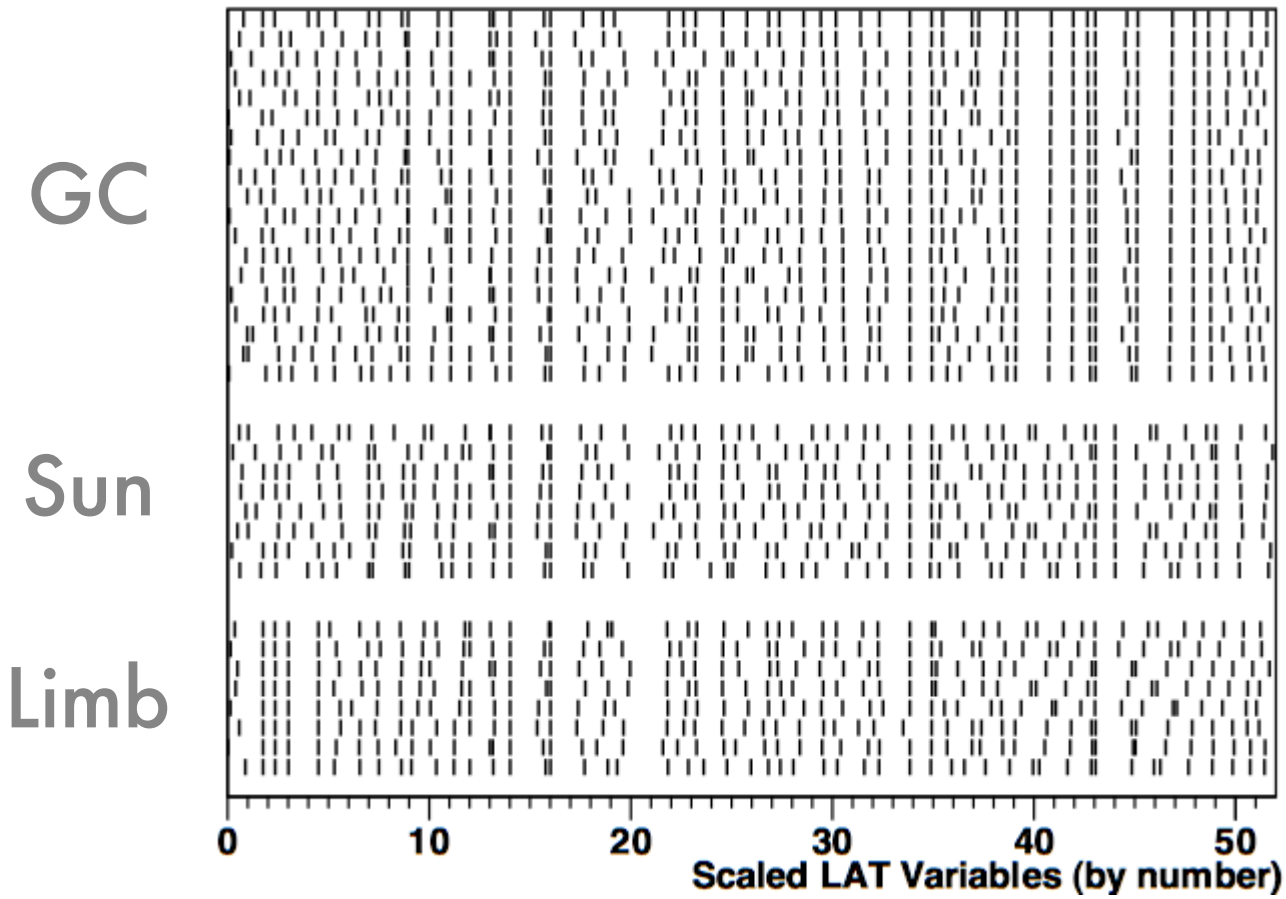
(2) Examine remainder of sky

Do those instrumental features produce a peak at 130?

GC
Sun
Sky-GC-Sun



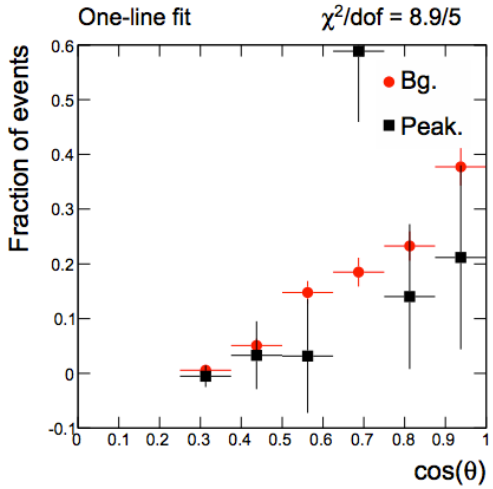
DNA …



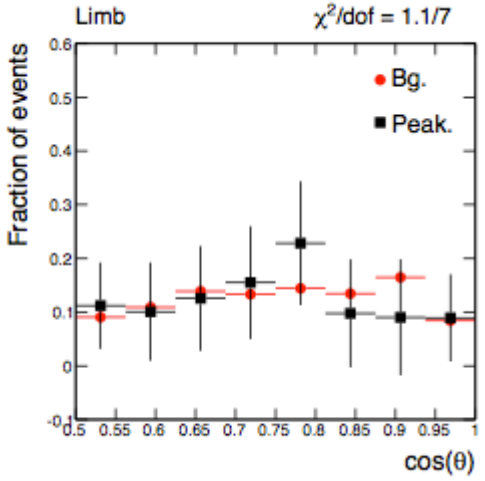
Common features?

Whiteson 1302.0427

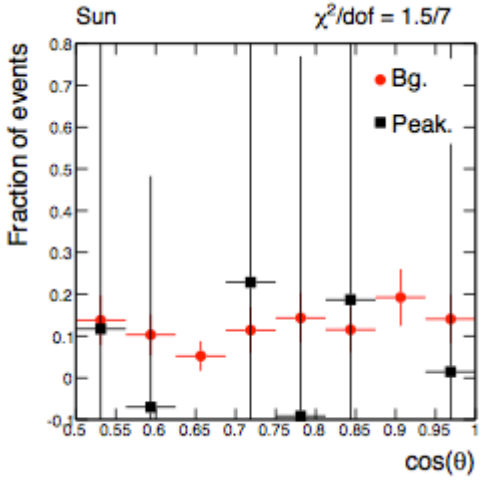
GC



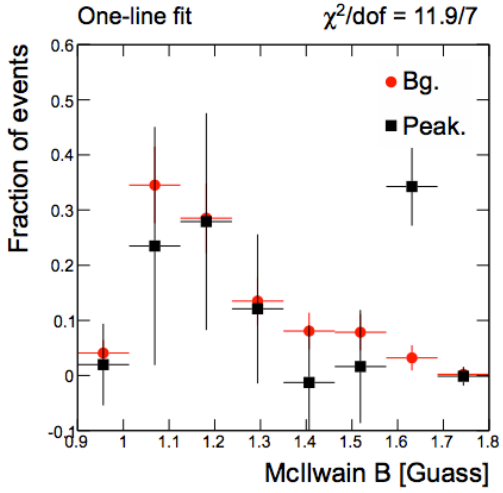
Limb



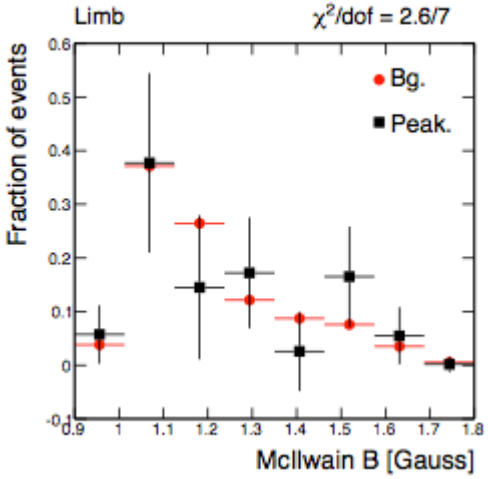
Sun



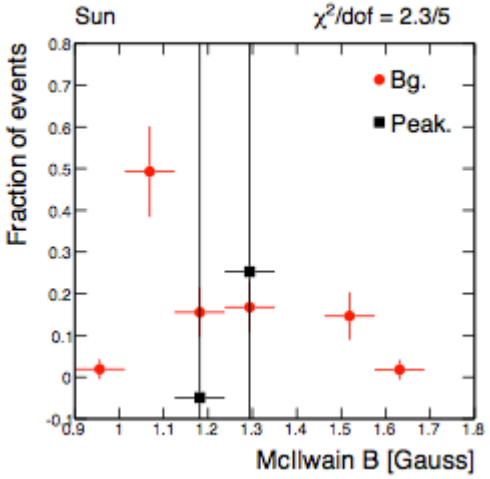
GC

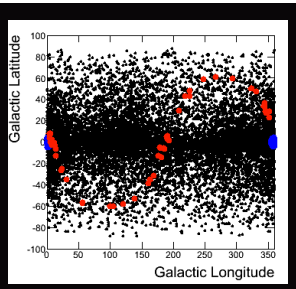


Limb



Sun

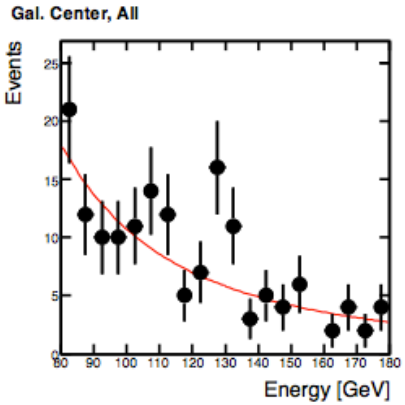
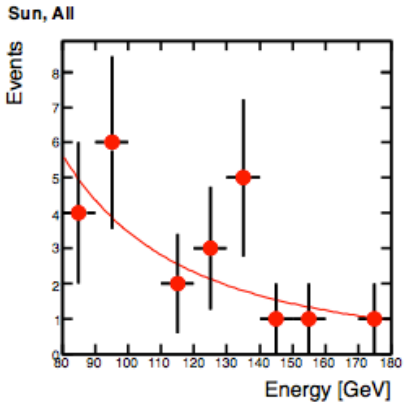
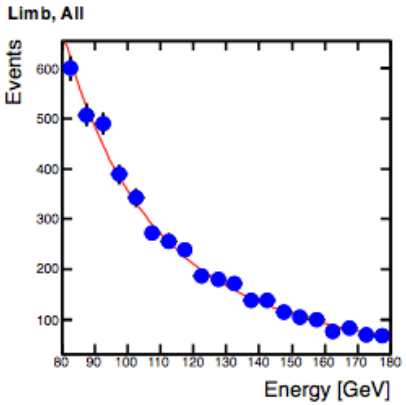
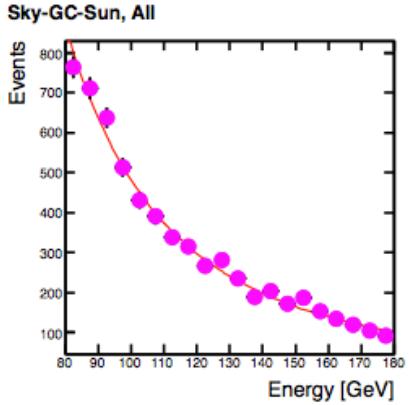


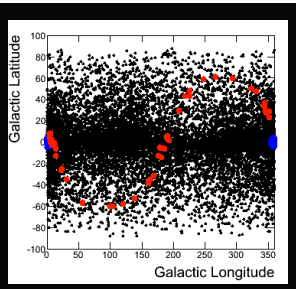


GC
Sun
Sky-GC-Sun

theta

Whiteson
1302.0427

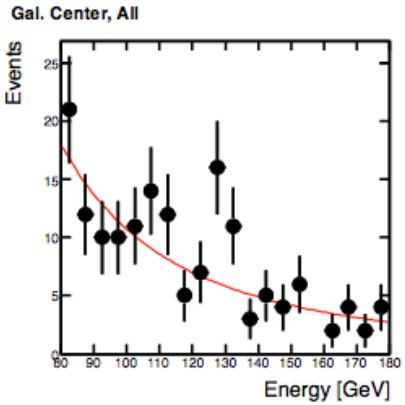
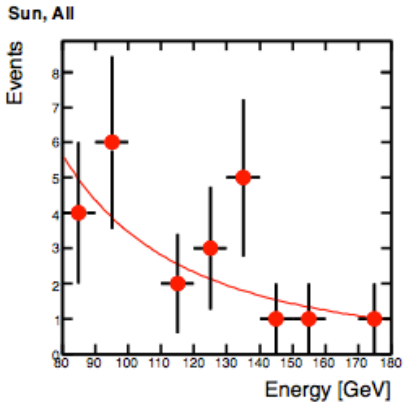
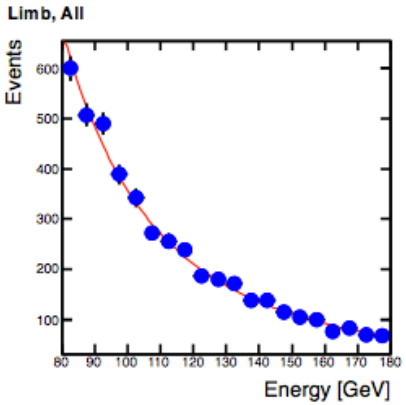
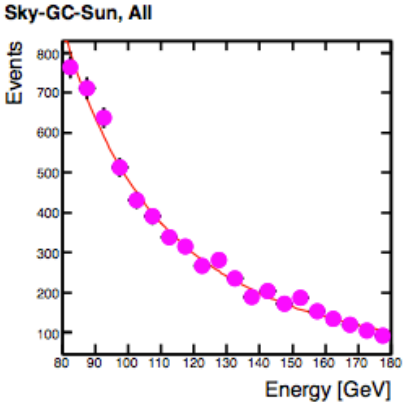
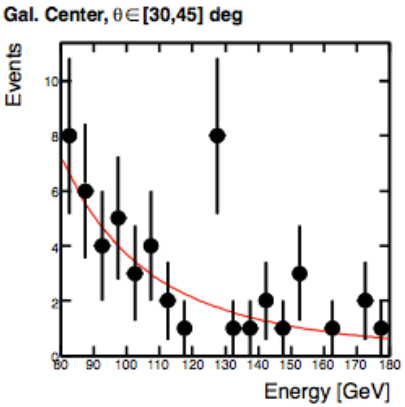
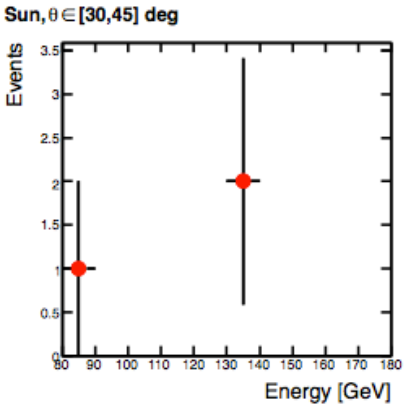
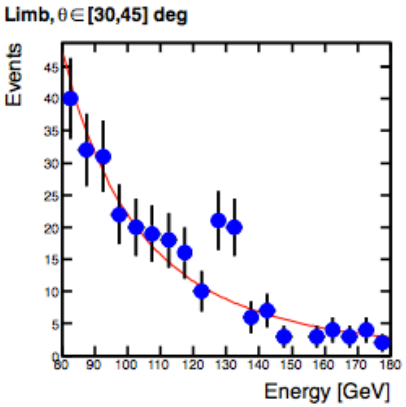
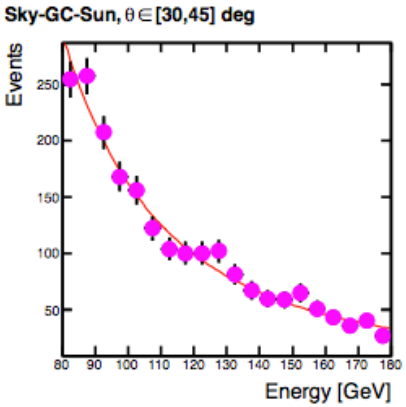
	GC	Sun	Limb	Sky-GC-Sun
All				

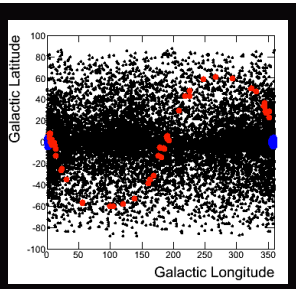


GC
Sun
Sky-GC-Sun

theta

Whiteson
1302.0427

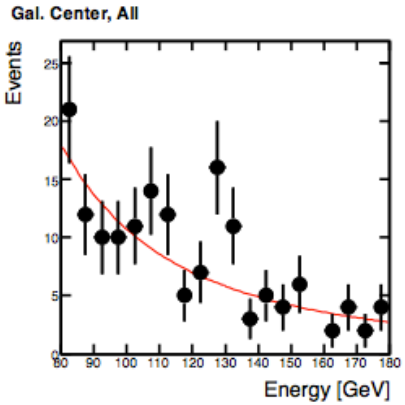
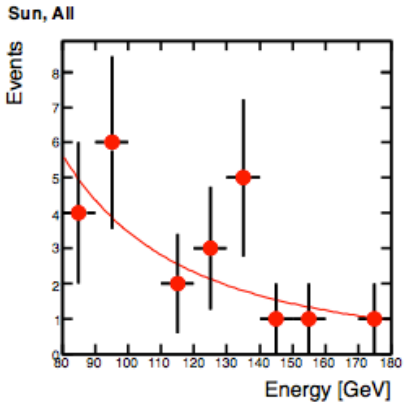
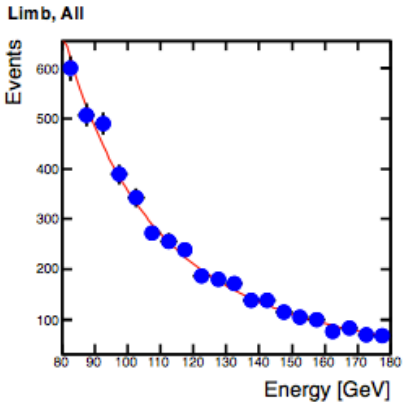
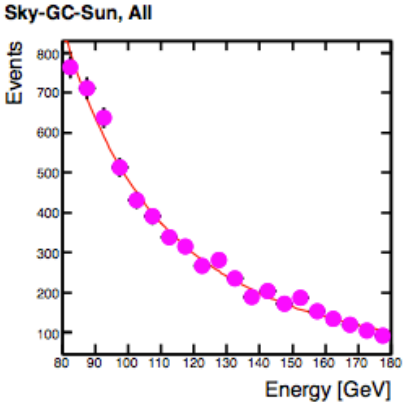
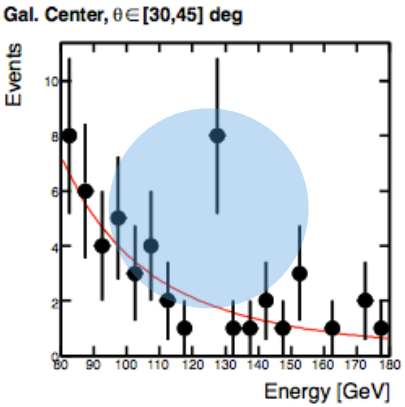
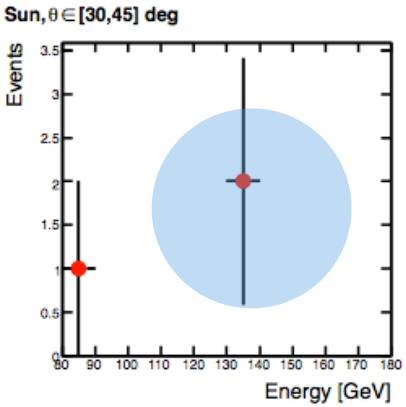
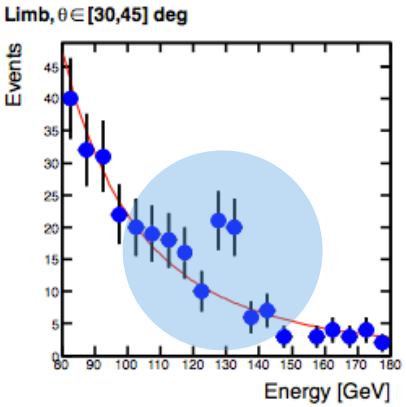
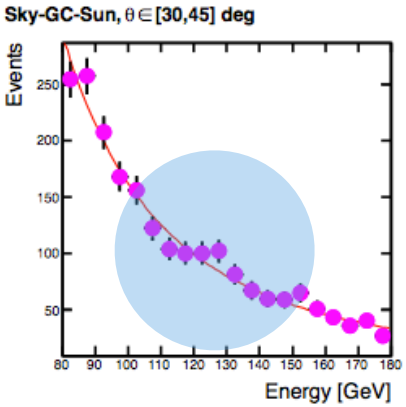
	GC	Sun	Limb	Sky-GC-Sun
All				
Theta [30,45]				



GC
Sun
Sky-GC-Sun

theta

Whiteson
1302.0427

	GC	Sun	Limb	Sky-GC-Sun
All				
Theta [30,45]				

Discussion

Theta restriction

- reveals Limb peak, feature in Sky-GC-Sun
- reduces GC, Solar peaks

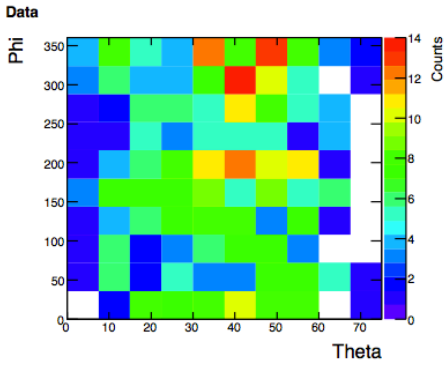
What is going on? One possibility:

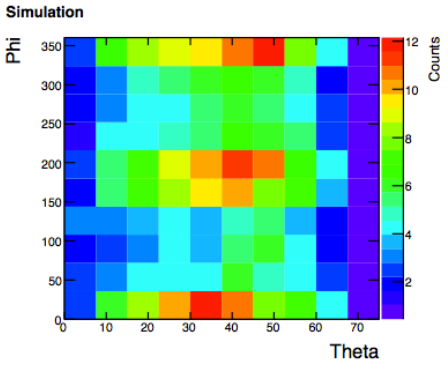
- Energy-dependent efficiency in some theta-phi space
- Sun/Limb/GC sweep out different paths in theta-phi space
-we see a hint in the sky spectrum just from theta

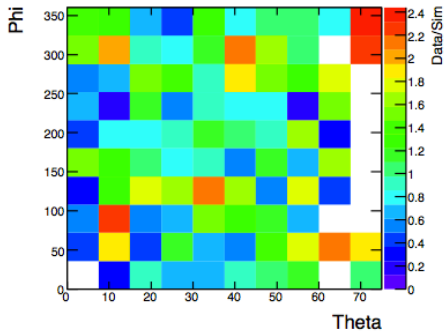
if we could identify theta-phi region,
might potentially enhance feature in sky

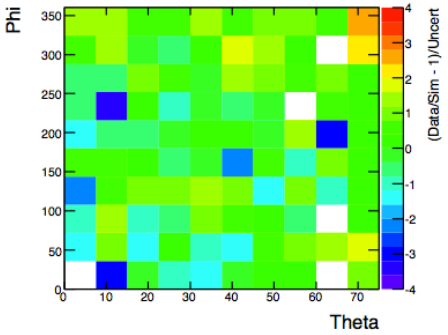
Simulation: GC

E>50

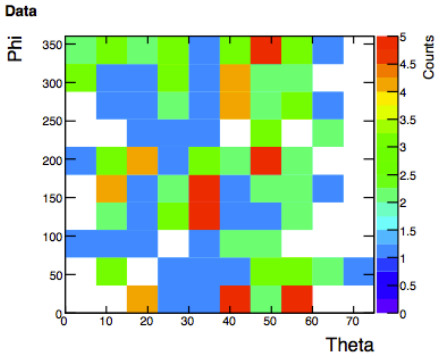


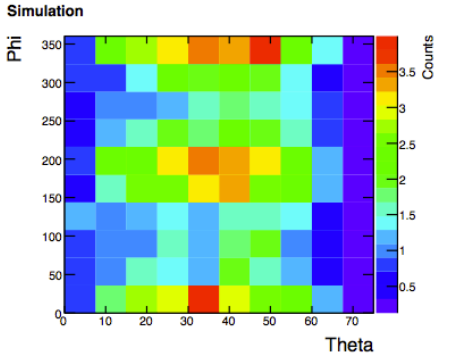


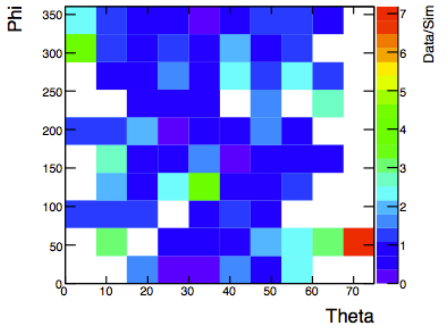


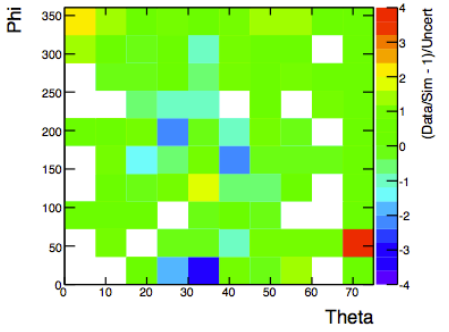


E>100



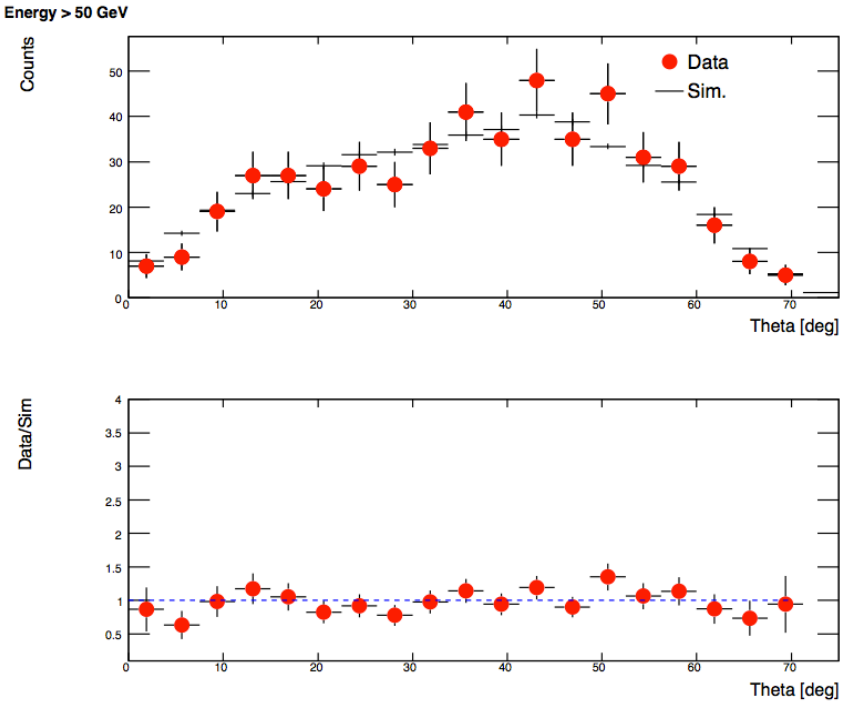




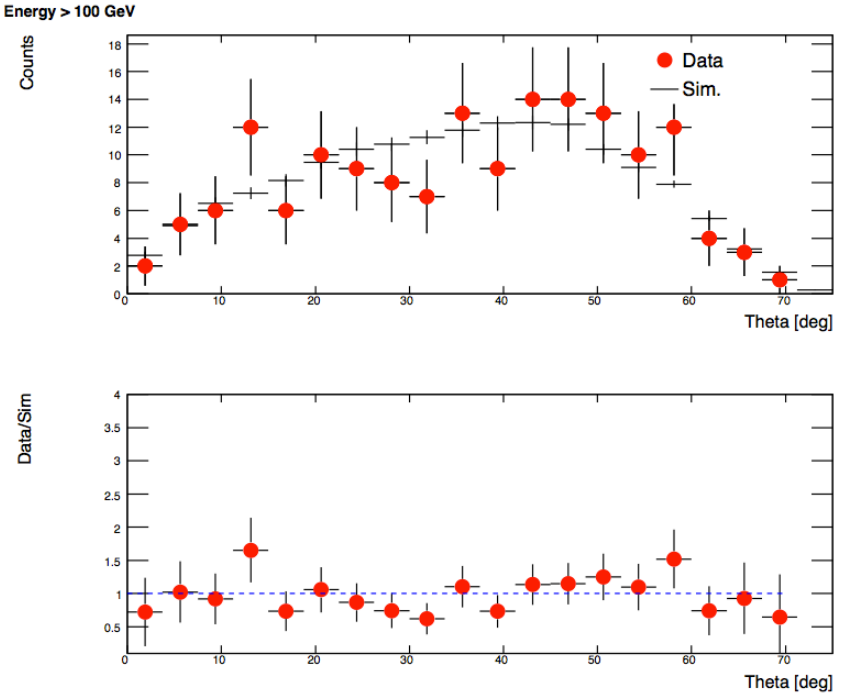


Simulation: GC

E>50



E>100

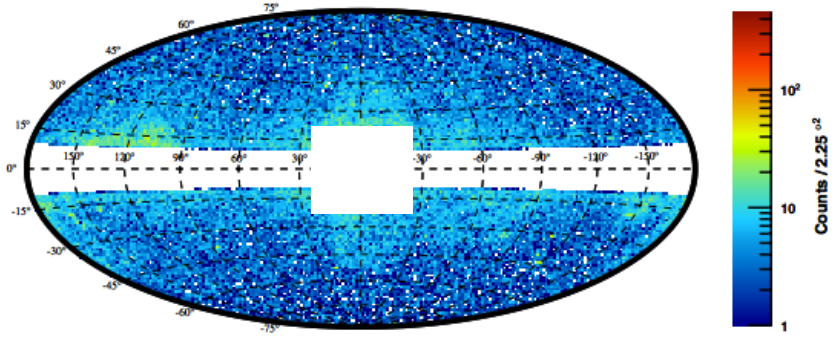


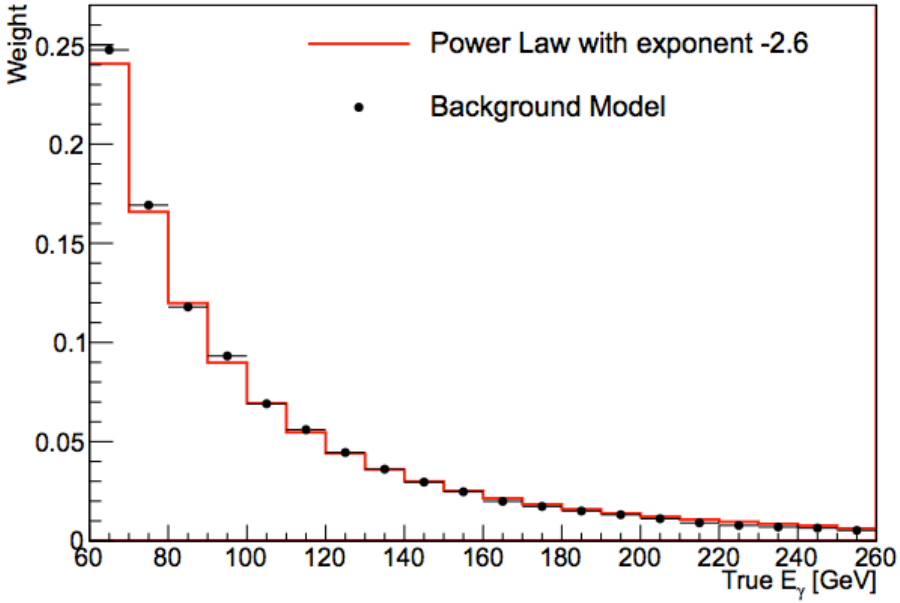
Background

Typical to assume a featureless power-law.

One test

Look away from DM density

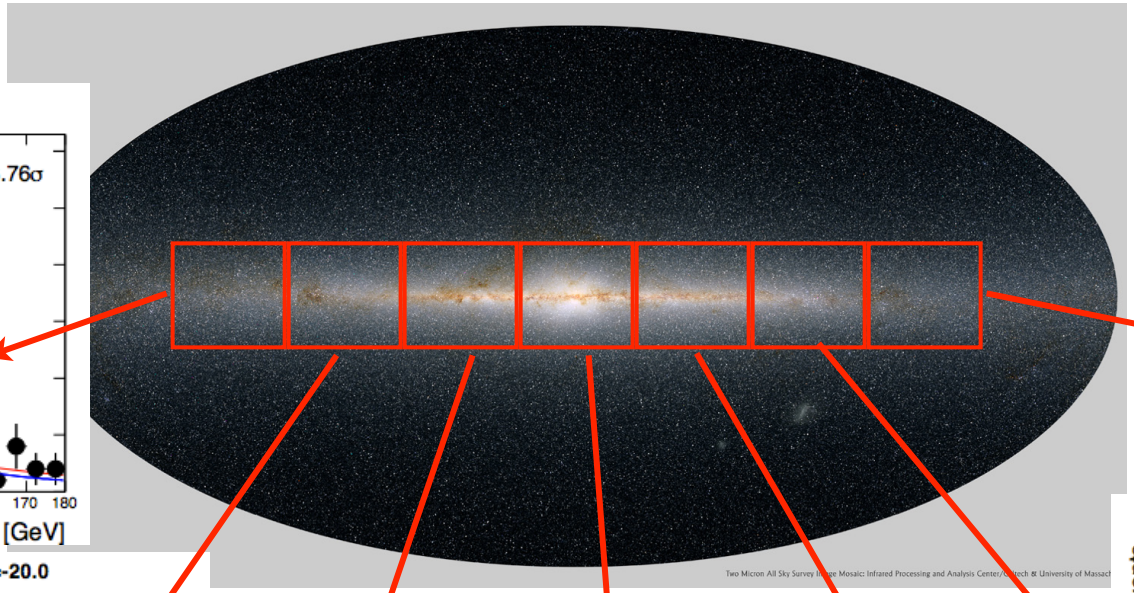




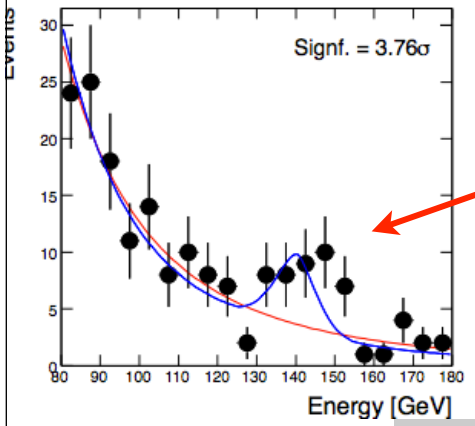
But

Can that describe the GC?

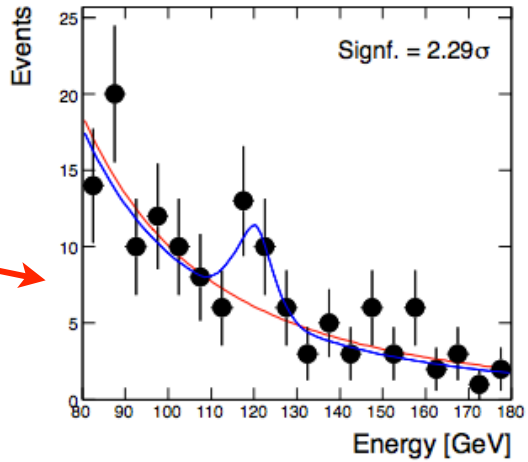
Rao & DW
1210.4934



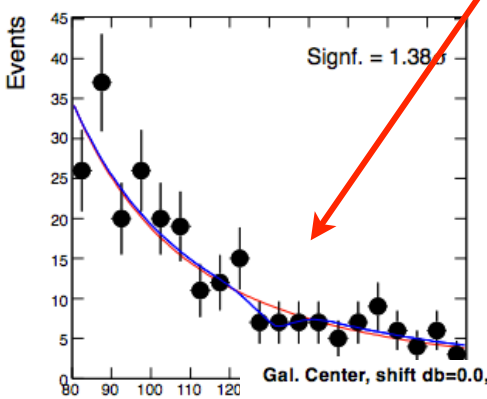
Gal. Center, shift db=0.0, dl=-30.0

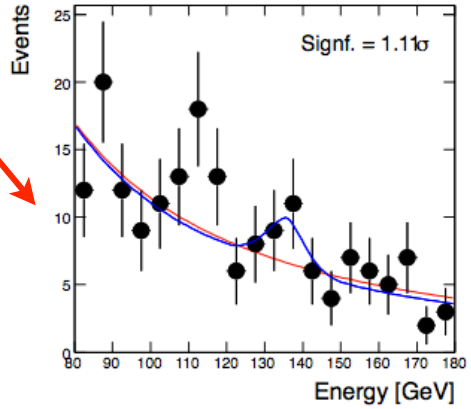


Gal. Center, shift db=0.0, dl=30.0

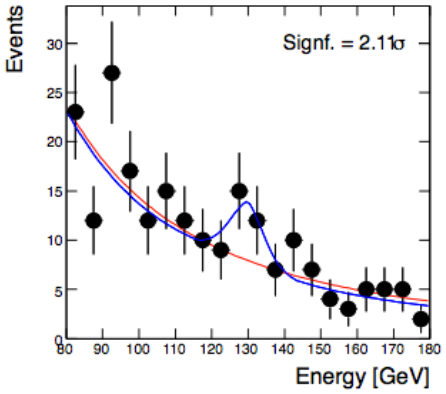


Gal. Center, shift db=0.0, dl=-20.0

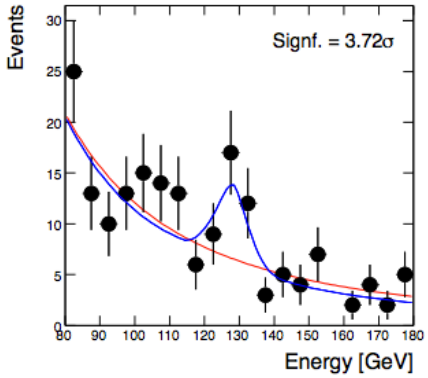




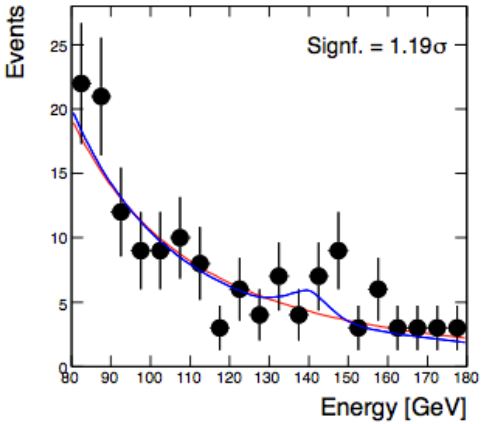
Gal. Center, shift db=0.0, dl=-10.0



Gal. Center, shift db=0.0, dl=0.0



Gal. Center, shift db=0.0, dl=10.0



more

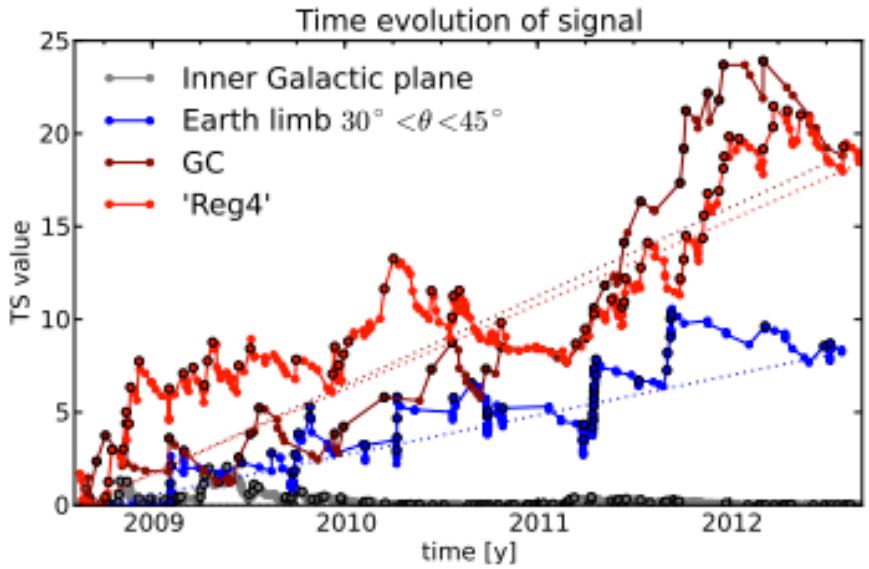
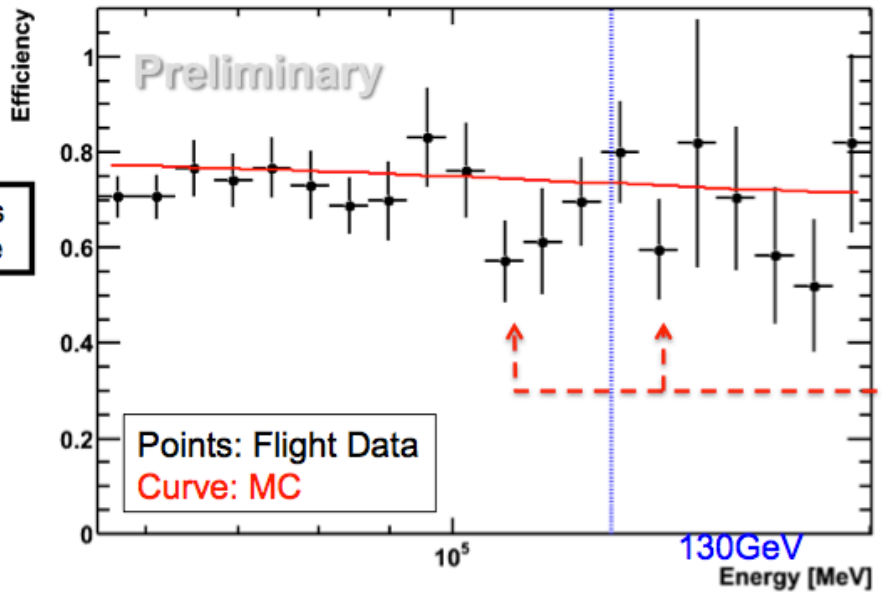


FIG. 9: Time evolution of TS values. In dark (light) red we show results for the GC region from Tab. II (respectively Reg4 from Ref. [21]), in blue we show the evolution of the Earth limb line. The gray line indicates for comparison the TS value obtained for the Inner Galactic plane, where no signal is observed.

Finkbiener, et al
1209.4562

Symposium

P7TRANSIENT to P7CLEAN Efficiency

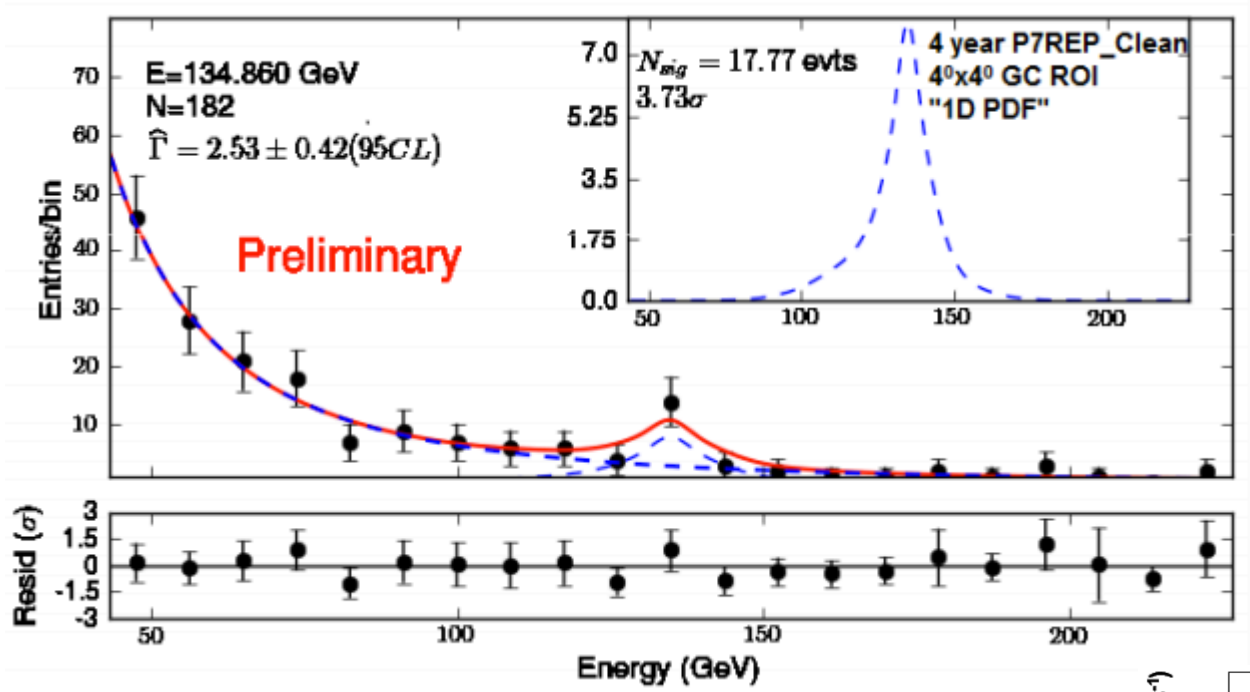


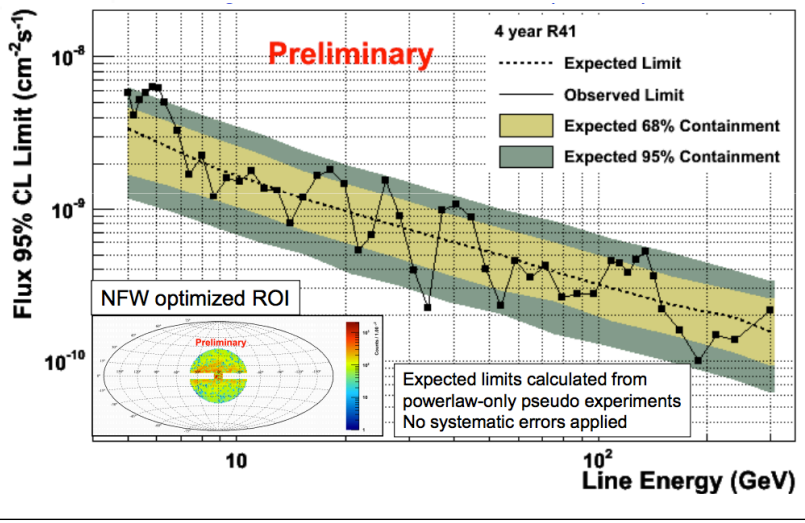
Same data as previous slide

These dips in efficiency appear to be related to the CAL-TRK agreement.

The efficiency at ~115Gev is 0.57/0.75 = 75% of the MC prediction. This would imply a 30% boost in signal at 130 GeV relative to the prediction from nearby energy bins.

Updated results

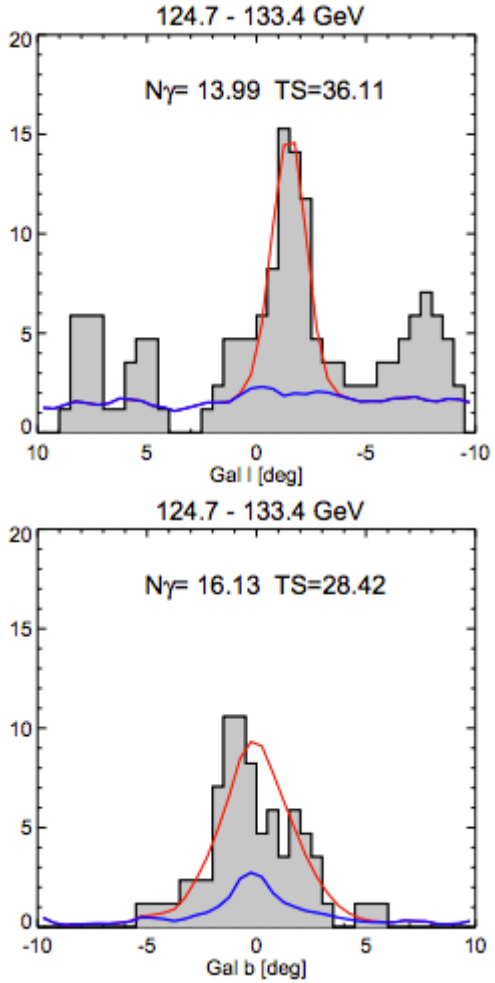


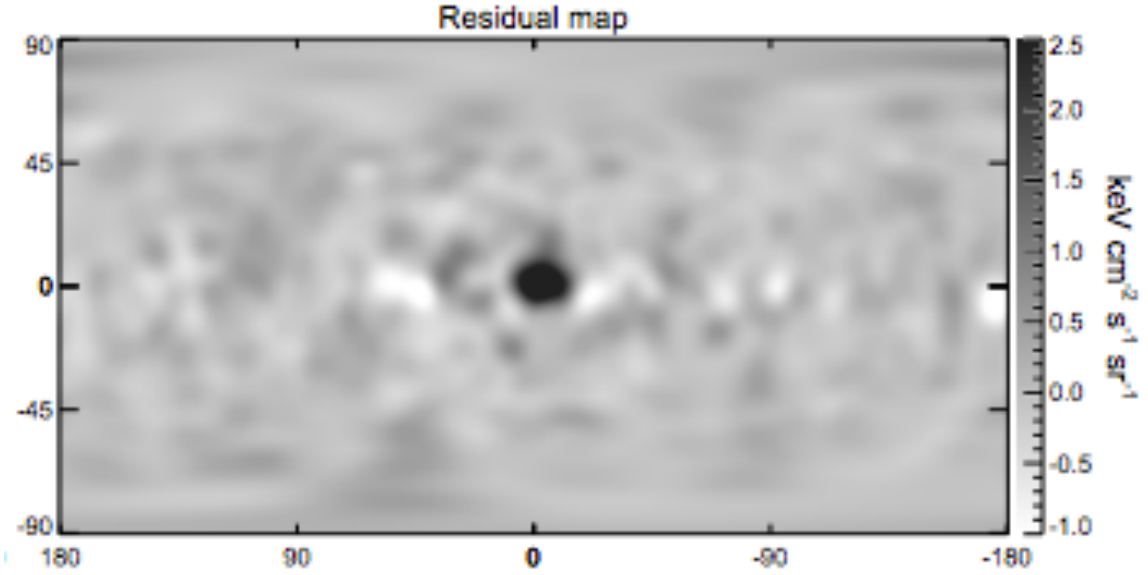


Outline

I. Introduction
II. The lines
III. One line or two?
IV. No continuum
V. Instrumental studies
VI. Source of the photons

Where are they from?

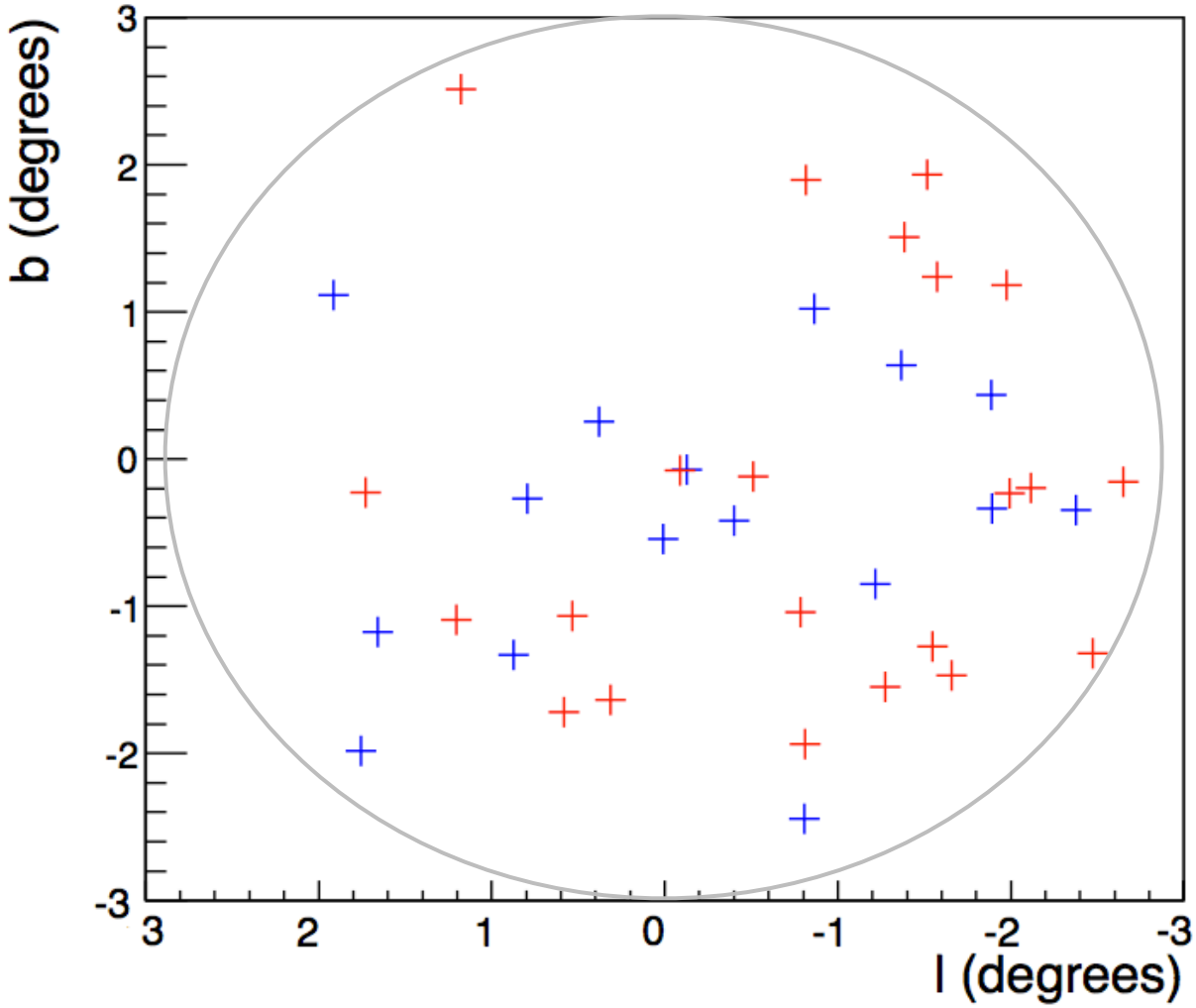




NFW density profile centered at $(\ell, b) = (-1.5°, 0°)$

Finkbiener&Su
1206.1616

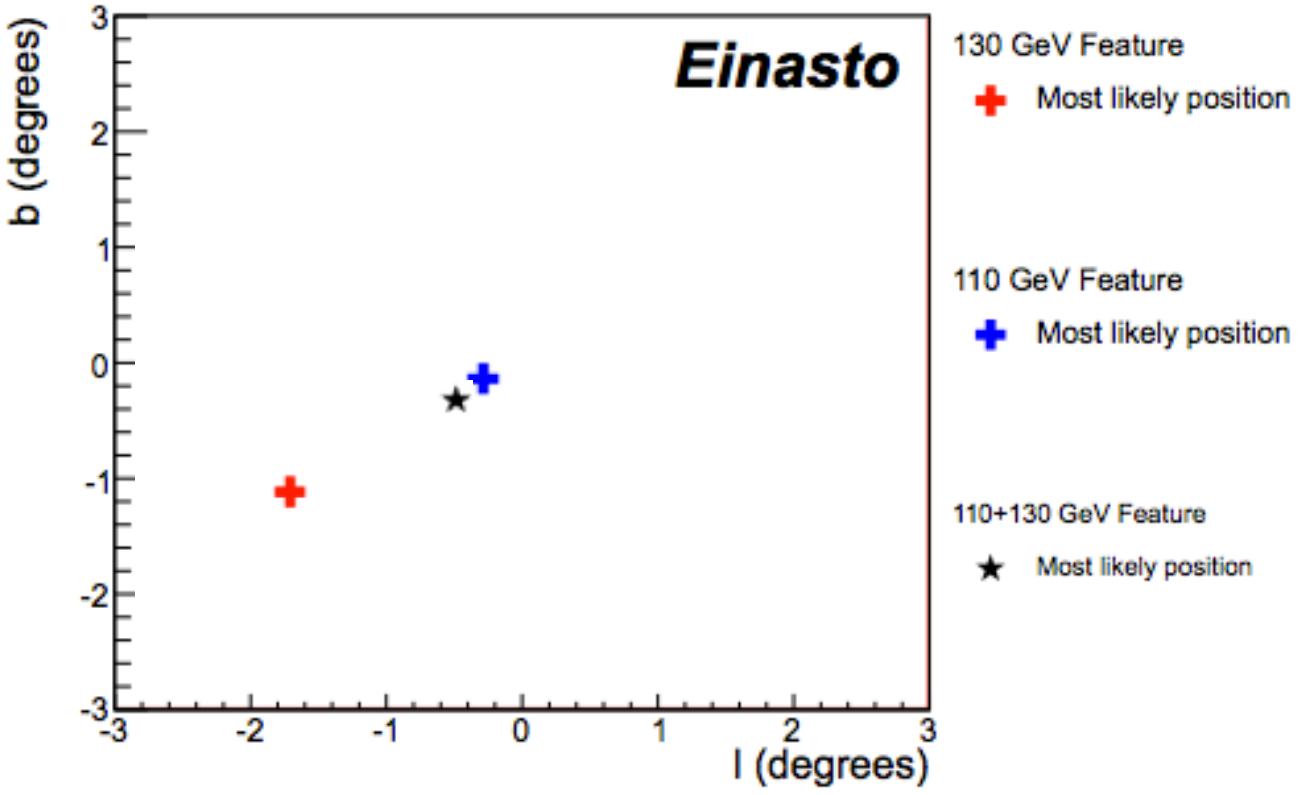
The photons



Following results use a 3-degree circle. Results are ~ the same for larger regions

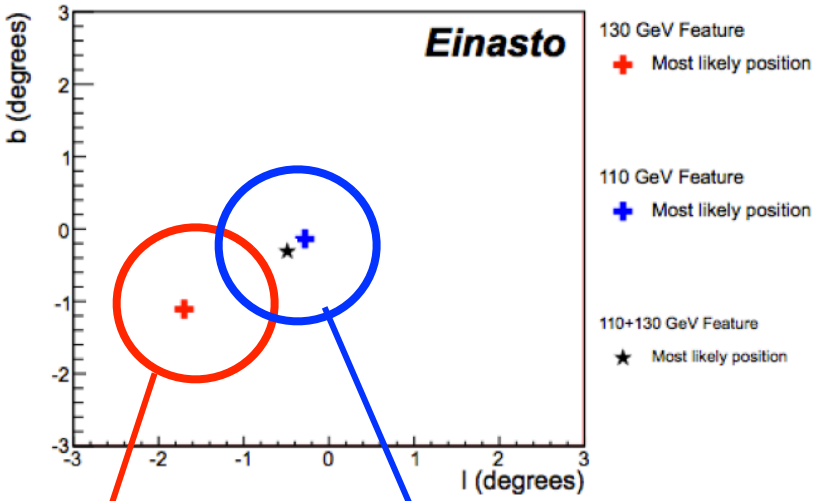
Rao & DW
1210.4934

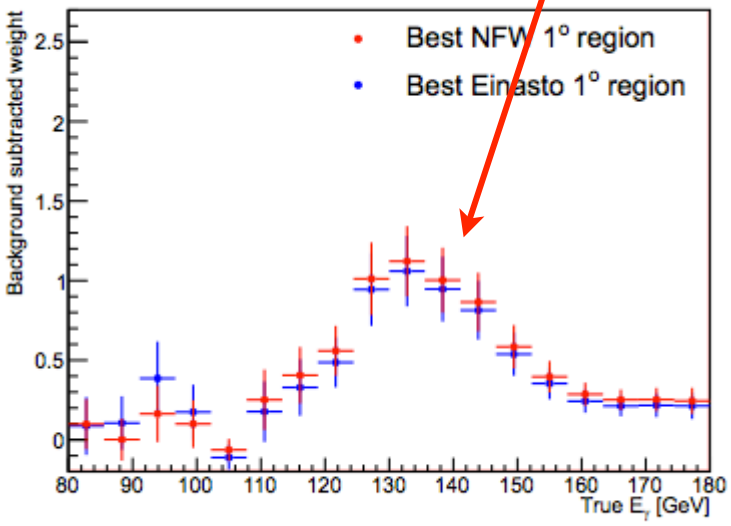
Locations

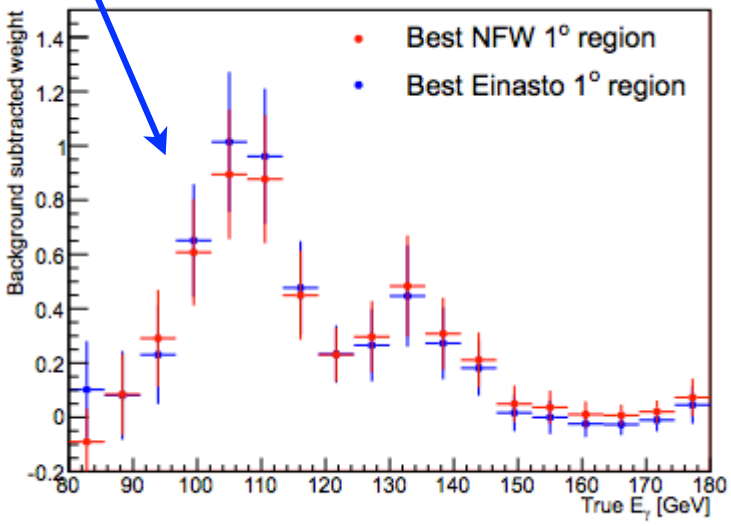


Rao & DW
1210.4934

Zoom: 1 degree

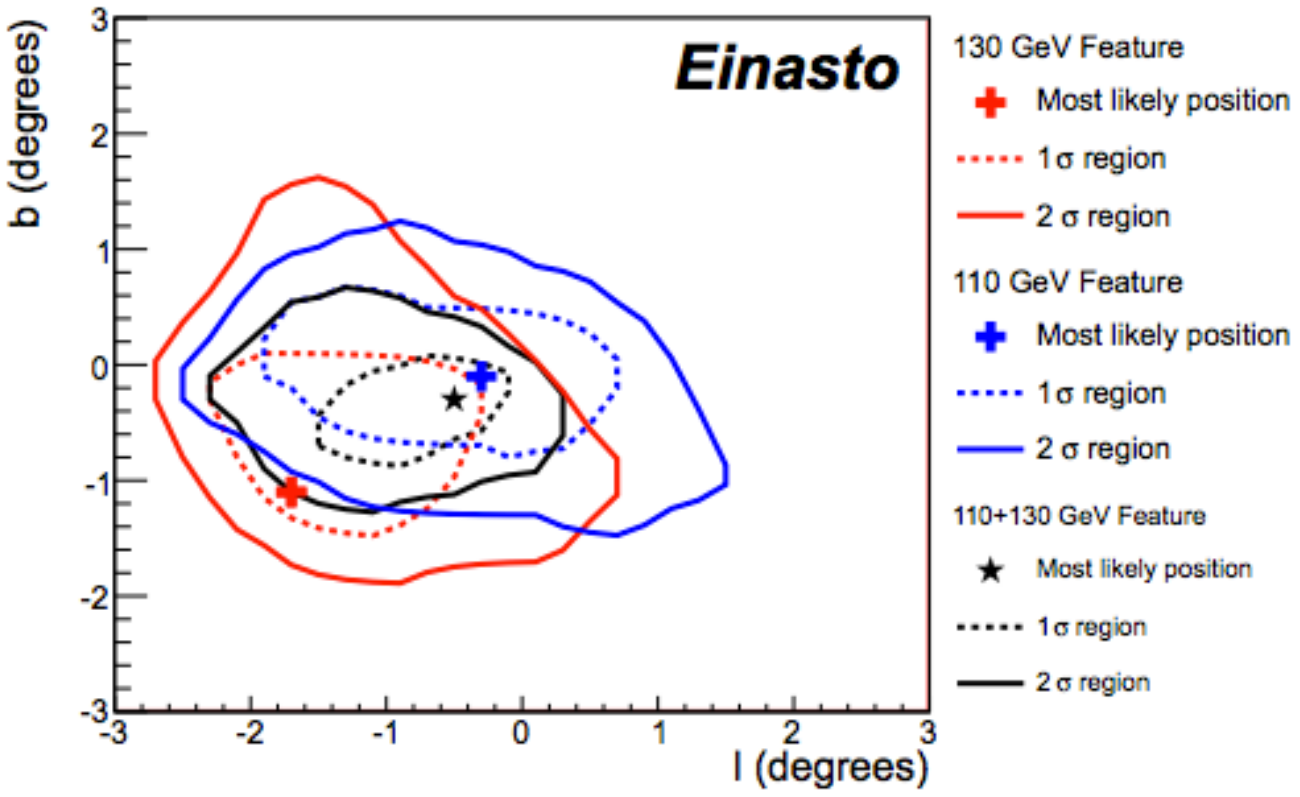






Rao & DW
1210.4934

Locations



Rao & DW
1210.4934

Questions

- Are the two features consistent with emission from a single source?
- Are the features consistent with emission from a dark matter halo at the galactic center?

Questions

- Are the two features consistent with emission from a single source?
- Are the features consistent with emission from a dark matter halo at the galactic center?

Hypothesis tests

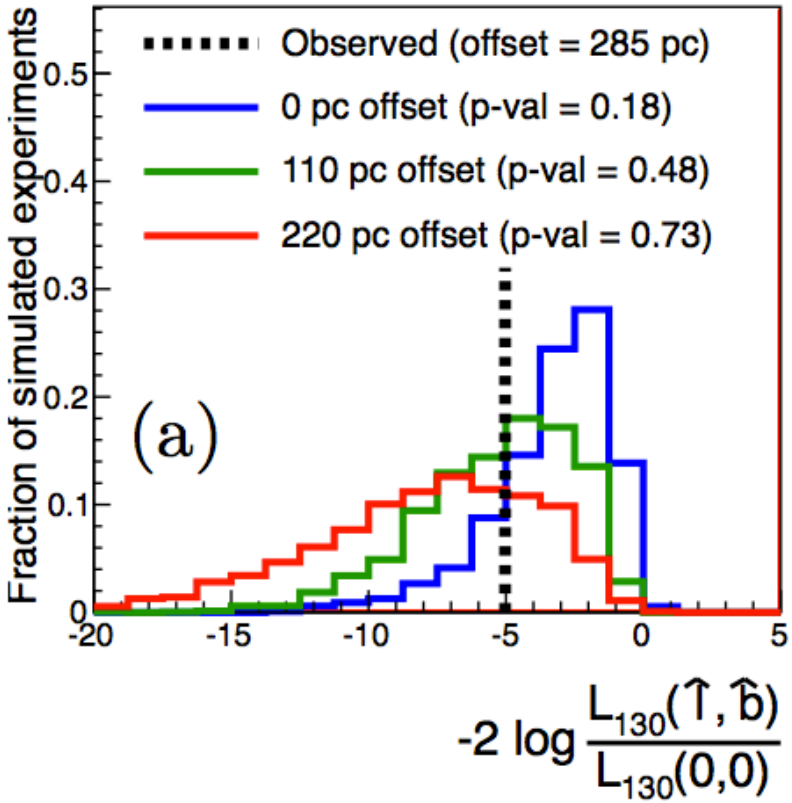
(l,b) fit far from GC

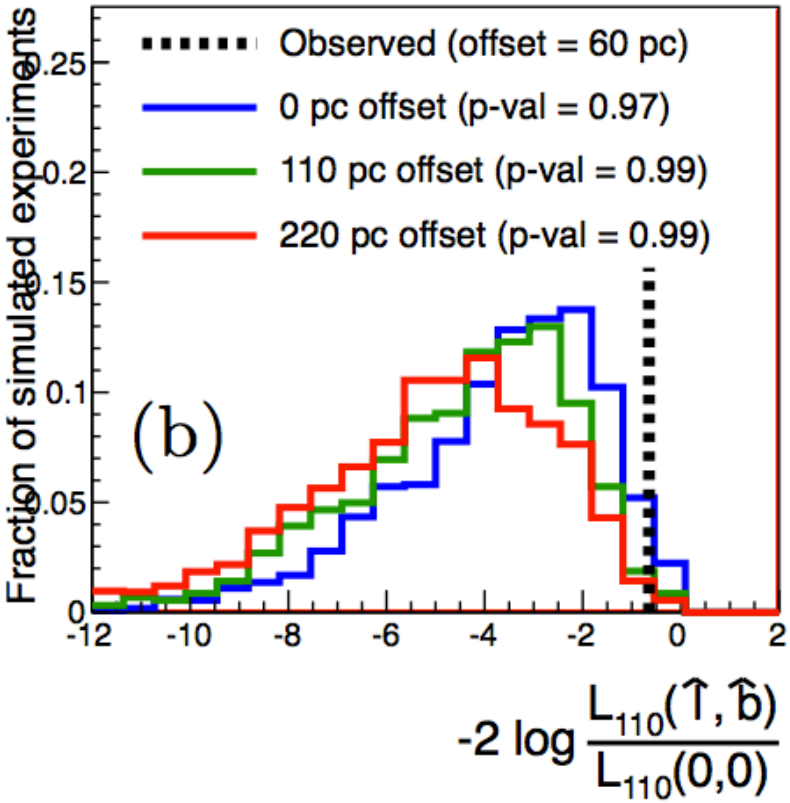
q → negative

$$q = -2 \log \frac{L(l = \hat{l}, b = \hat{b})}{L(l = 0, b = 0)}$$

(l,b) fit is close to 0,0

q → zero





Questions

- Are the two features consistent with emission from a single source?
- Are the features consistent with emission from a dark matter halo at the galactic center?

Hypothesis tests

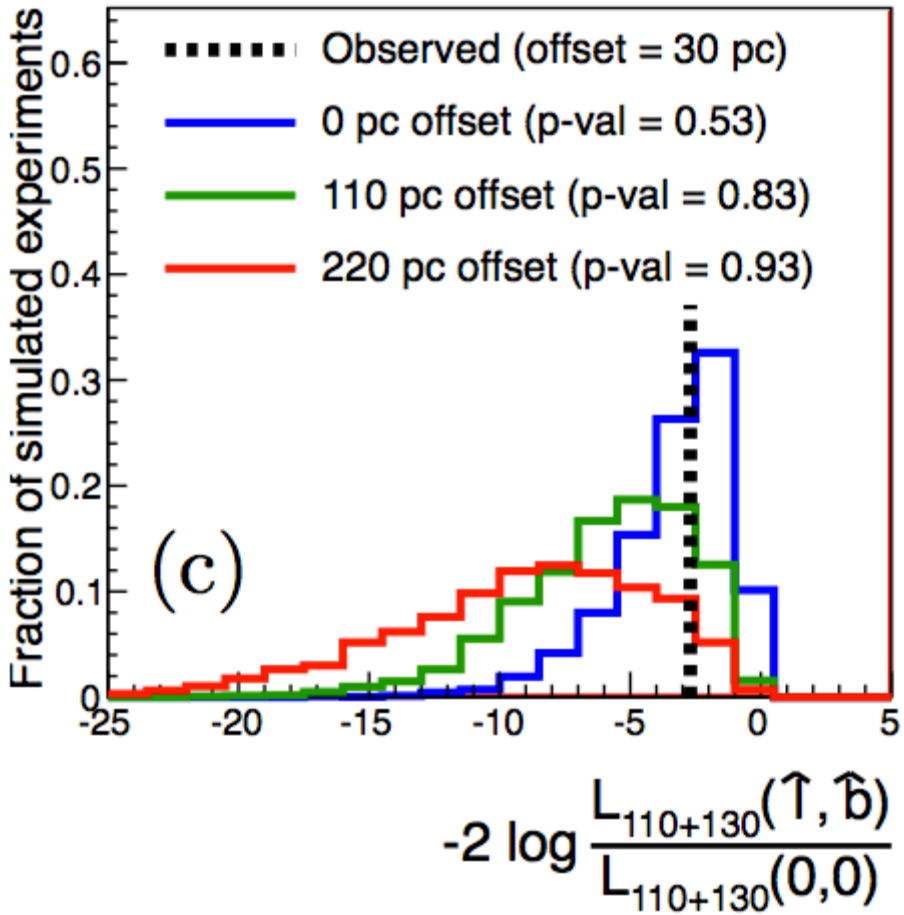
(l,b) fit far from GC

q → negative

$$q = -2 \log \frac{L(l = \hat{l}, b = \hat{b})}{L(l = 0, b = 0)}$$

(l,b) fit is close to 0,0

q → zero



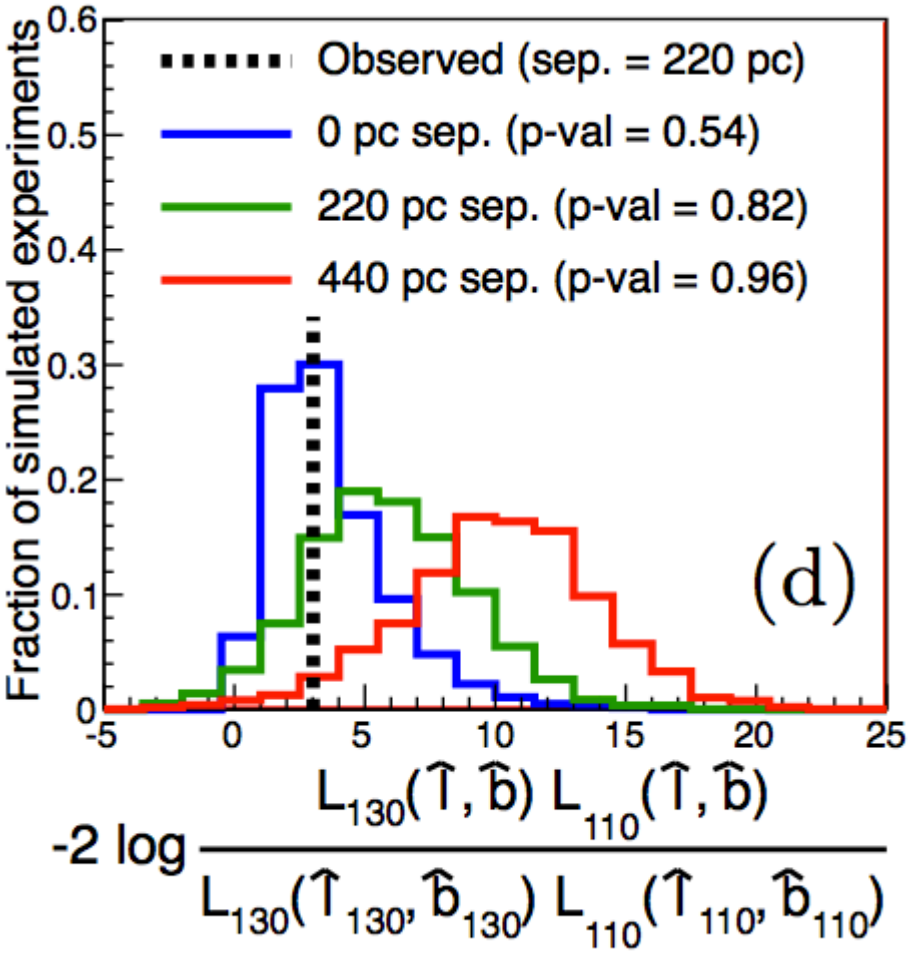
Hypothesis tests

separate fits are better

q → larger

joint fit is better

q → smaller



Locations

Conclusion:

The photon locations are easily consistent with a single DM halo at the GC

Hinchliffe's Rule

The Fermi Lines

Are they real?

If the title is a question, the answer is 'no'.

受入
90-7-95
高工研図書室

IS HINCHLIFFE'S RULE TRUE? ·

Boris Peon

Abstract

Hinchliffe has asserted that whenever the title of a paper is a question with a yes/no answer, the answer is always no. This paper demonstrates that Hinchliffe's assertion is false, but only if it is true.

Conclusions

Supporting evidence

Features
- strong stat power

Locations
- consistent with GC

No instrumental problems
- identified *so far*
- some *hints in theta, B*

Concerns

Background assumptions
- fair to assume featureless?

No Continuum
- requires some theory gymnastics

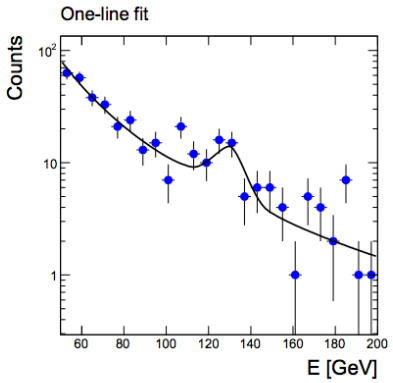
Limb, solar signals
- need resolution

Backup

Sensitivity

Whiteson
1208.3677

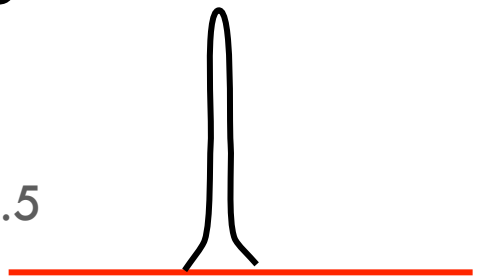
Discriminating var



Unfolding var

Background: flat

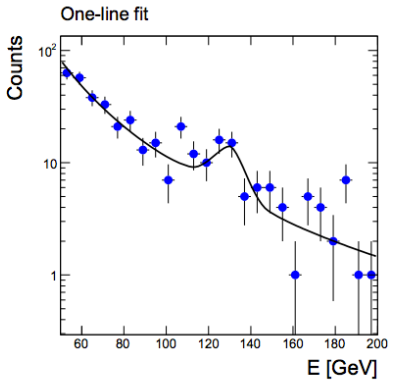
Signal: delta func at 0.5



Sensitivity

Whiteson 1208.3677

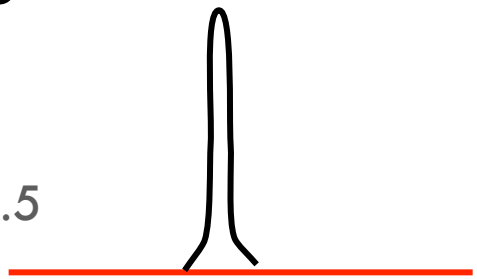
Discriminating var

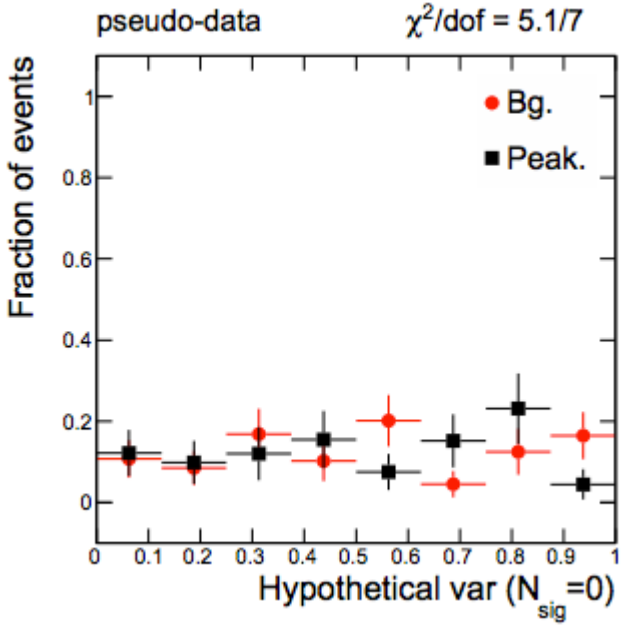


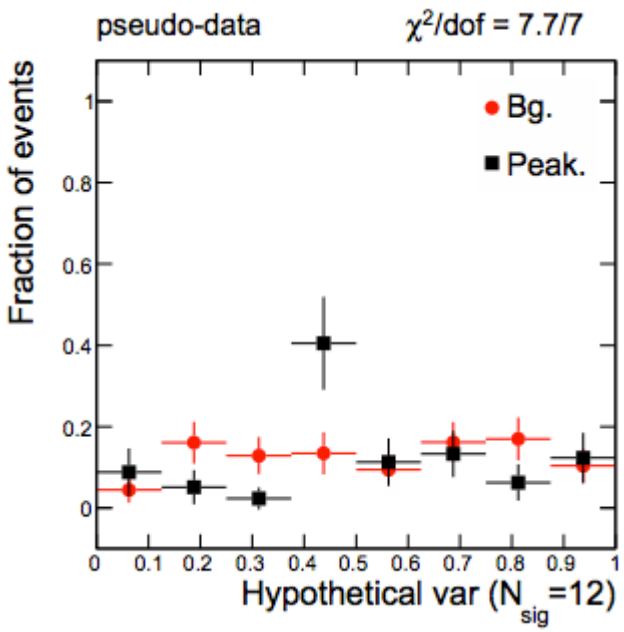
Unfolding var

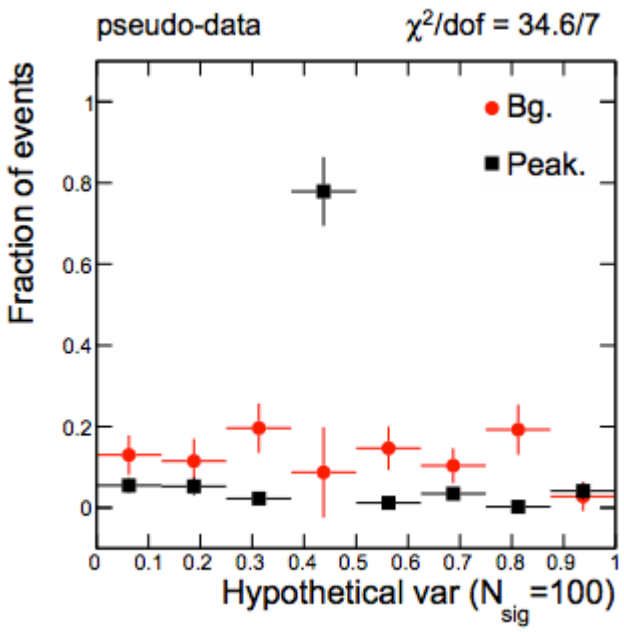
Background: flat

Signal: delta func at 0.5

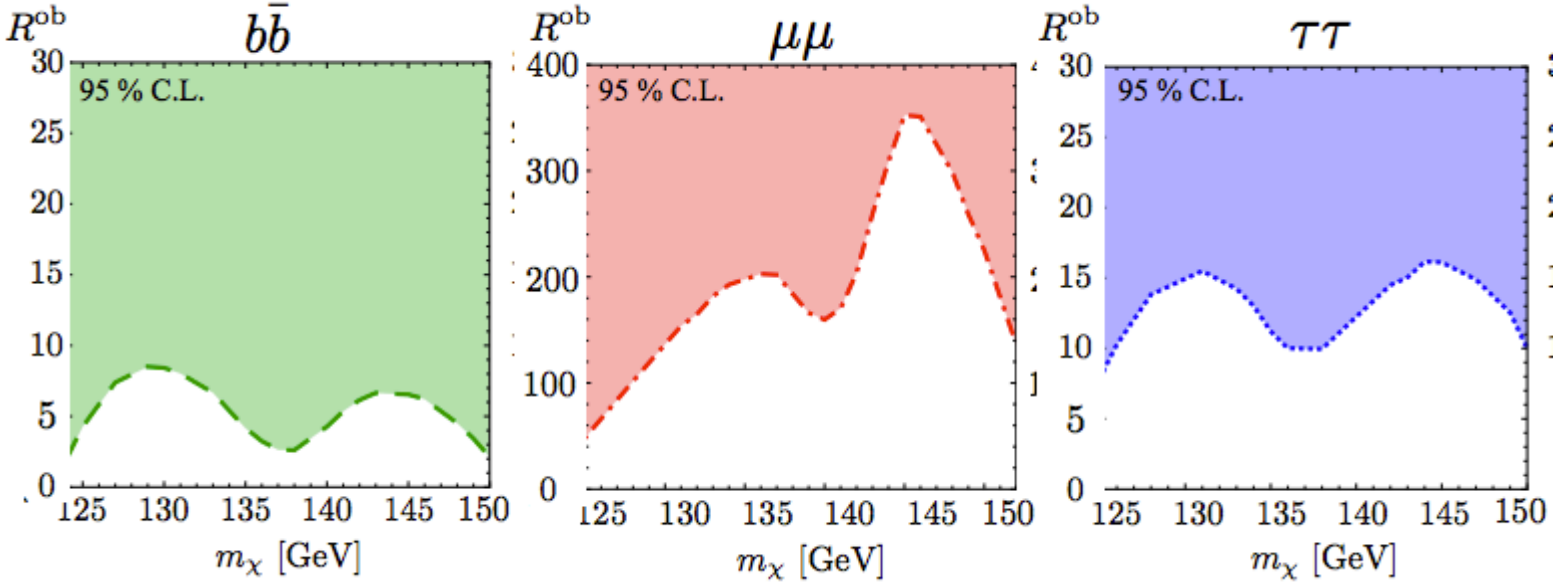








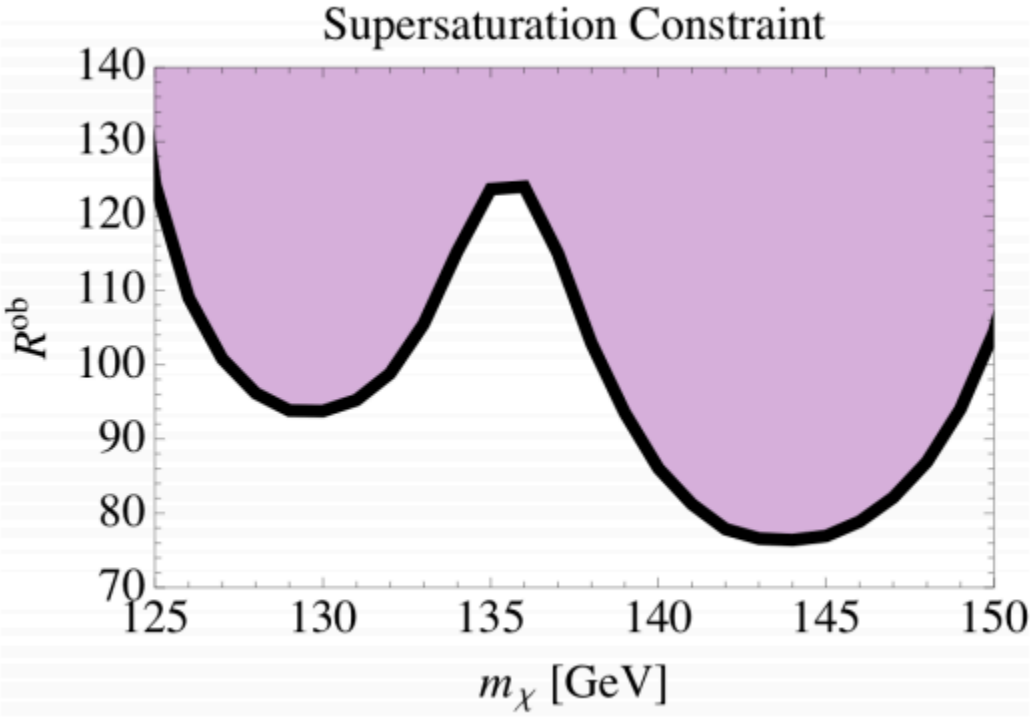
Continuum

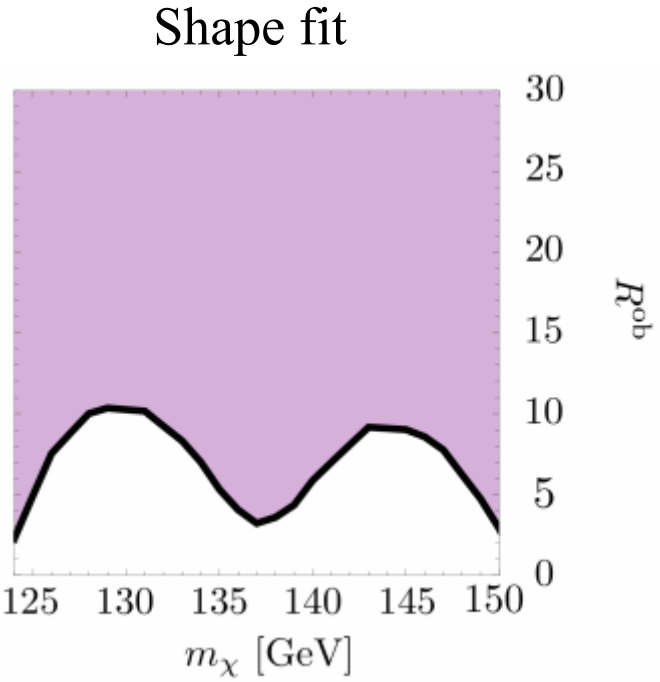


Lisanti, IDM2012

How much?

WW





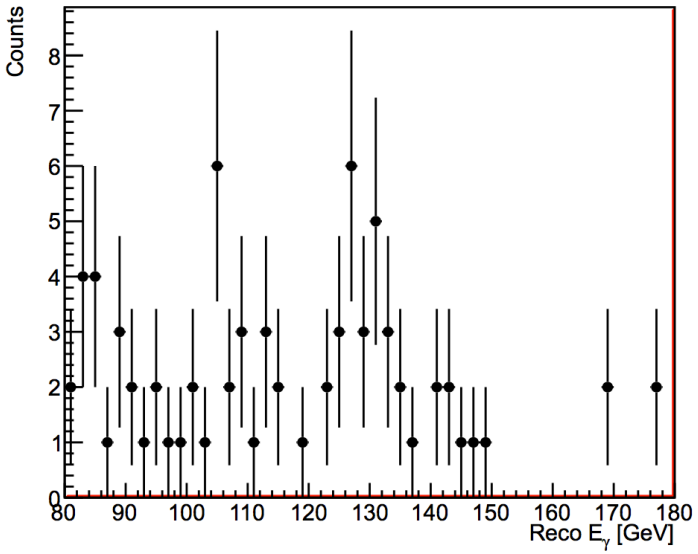
$$R^{\rm th} \equiv \frac{\sigma_{\rm ann}}{2\,\sigma_{\gamma\gamma} + \sigma_{\gamma Z}}$$

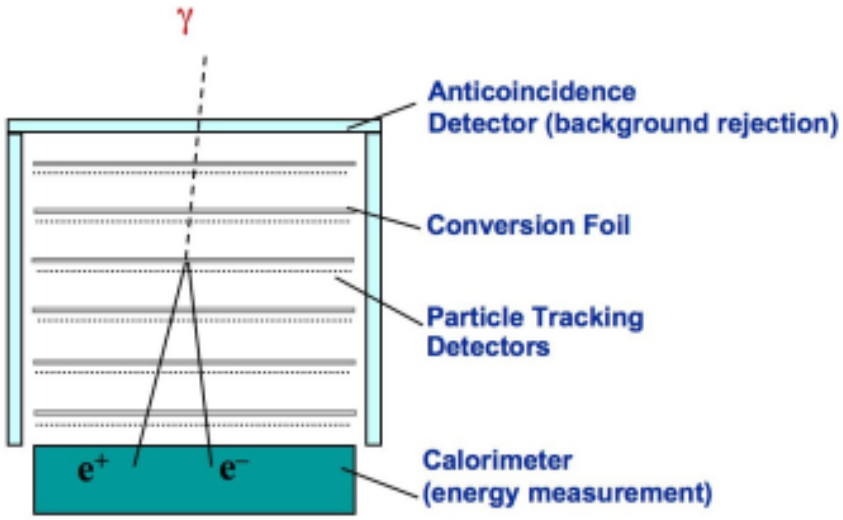
Large R: little ϒϒ+ϒZ

Small R: mostly ϒϒ+ϒZ

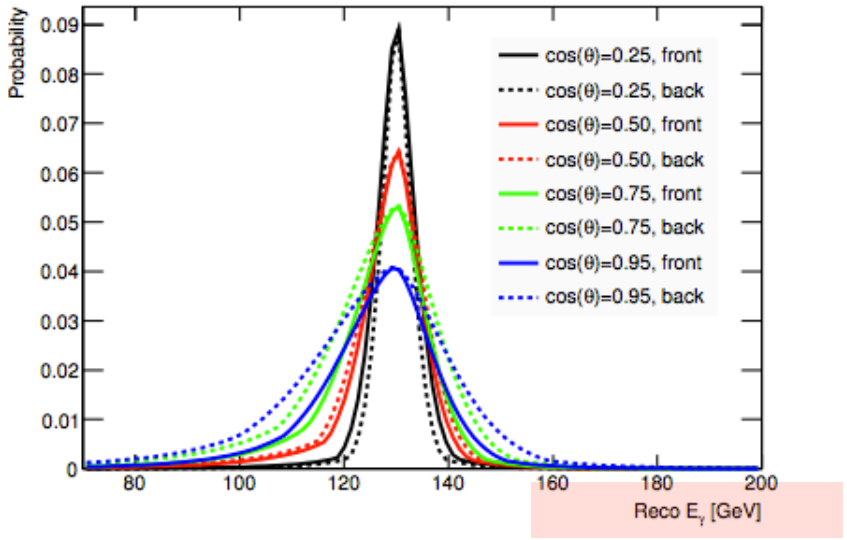
Cohen et al 1207.0800

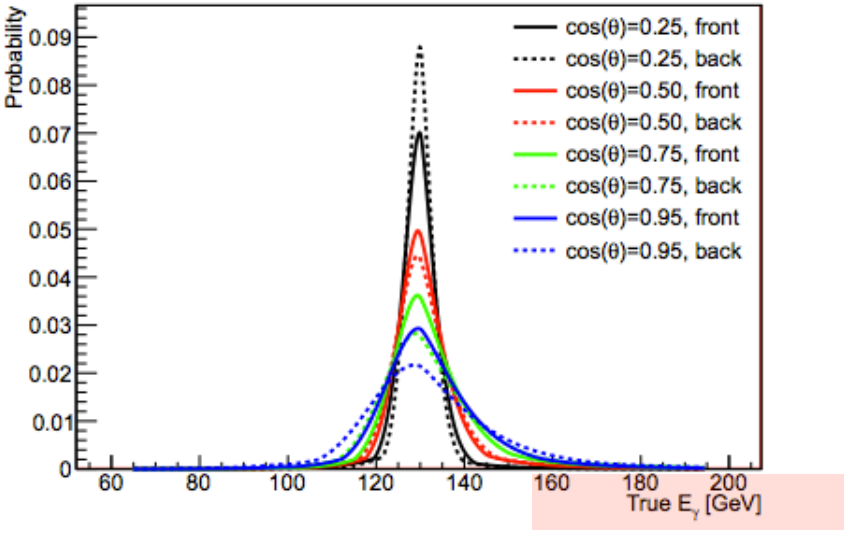
angles

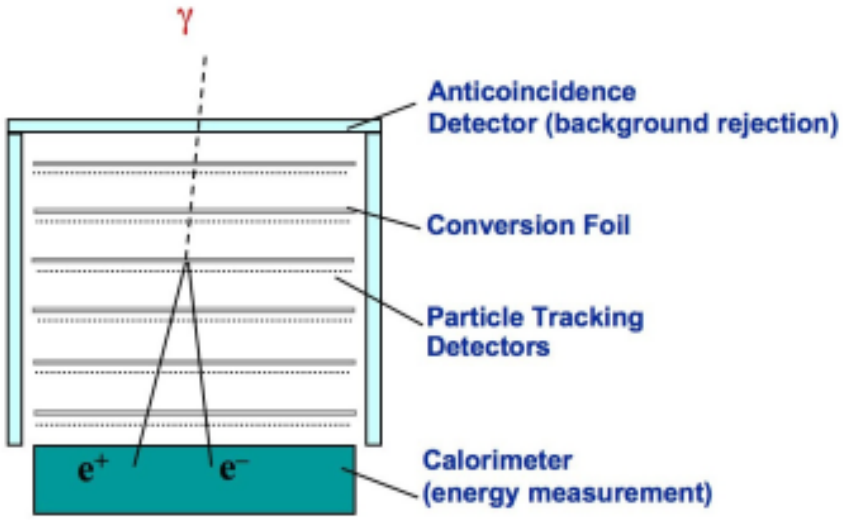

Counts
0
1
2
3
4
5
6
7
8
80
90
100
110
120
130
140
150
160
170
180
Reco E_γ [GeV]


γ
Anticoincidence
Detector (background rejection)
Conversion Foil
Particle Tracking
Detectors
e+
e−
Calorimeter
(energy measurement)

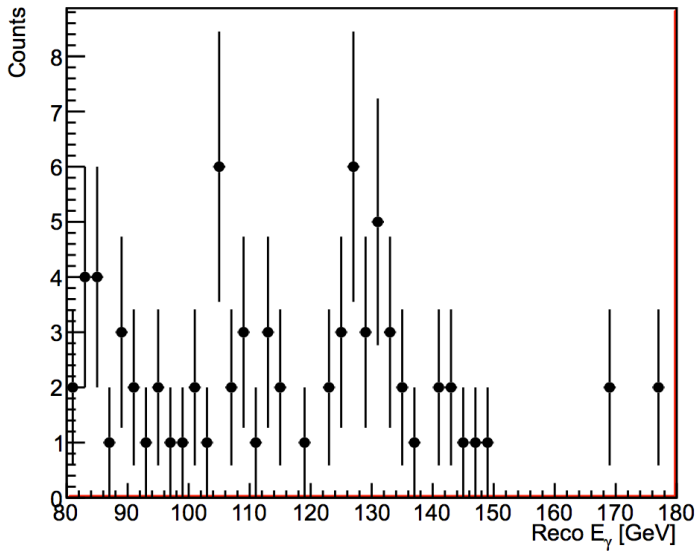
Angles


Probability
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
80
100
120
140
160
180
200
Reco E$_\gamma$ [GeV]
cos(θ)=0.25, front
cos(θ)=0.25, back
cos(θ)=0.50, front
cos(θ)=0.50, back
cos(θ)=0.75, front
cos(θ)=0.75, back
cos(θ)=0.95, front
cos(θ)=0.95, back

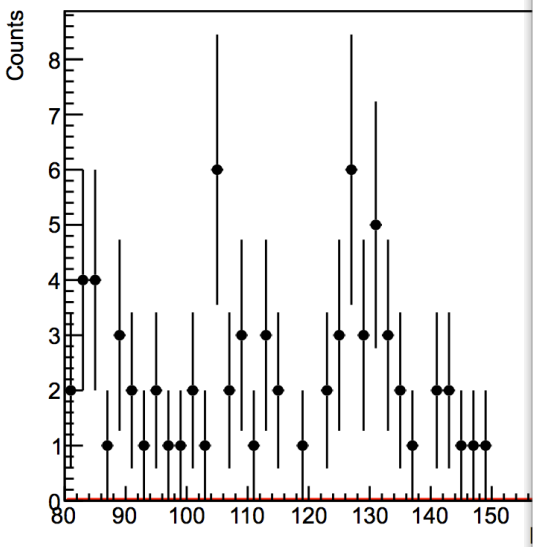

Probability
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
60
80
100
120
140
160
180
200
True E$_\gamma$ [GeV]
cos(θ)=0.25, front
cos(θ)=0.25, back
cos(θ)=0.50, front
cos(θ)=0.50, back
cos(θ)=0.75, front
cos(θ)=0.75, back
cos(θ)=0.95, front
cos(θ)=0.95, back

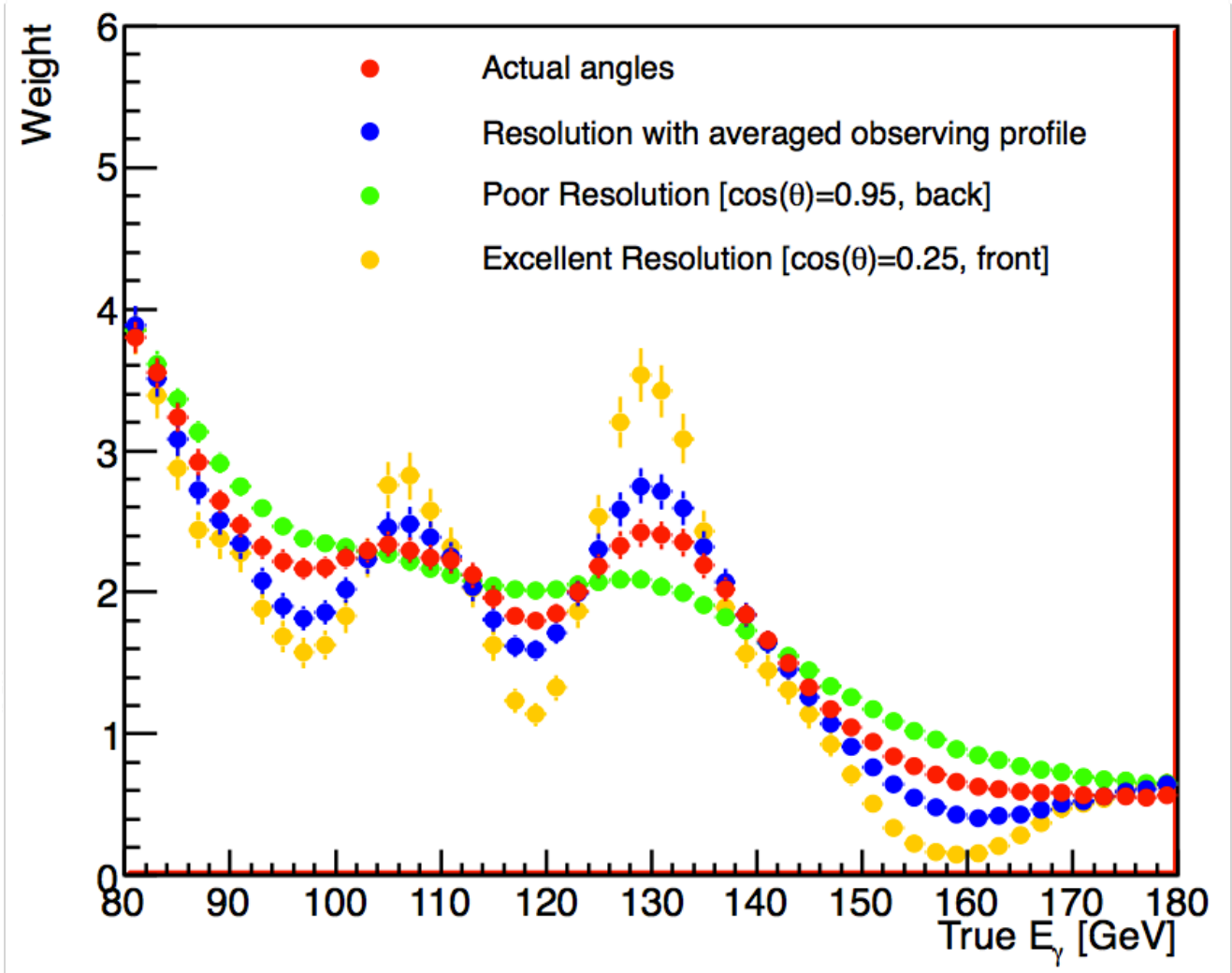

γ
Anticoincidence
Detector (background rejection)
Conversion Foil
Particle Tracking
Detectors
e+
e−
Calorimeter
(energy measurement)

Angles


Counts
0
1
2
3
4
5
6
7
8
80
90
100
110
120
130
140
150
160
170
180
Reco E_γ [GeV]

Angles


Counts
0
1
2
3
4
5
6
7
8
80
90
100
110
120
130
140
150


Weight
Actual angles
Resolution with averaged observing profile
Poor Resolution [cos(θ)=0.95, back]
Excellent Resolution [cos(θ)=0.25, front]
0
1
2
3
4
5
6
80
90
100
110
120
130
140
150
160
170
180
True E$_\gamma$ [GeV]